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GASIFICATION AND PETROGRAPHIC STUDIES OF SASKATCHEWAN LIGNITES

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Summary

Samples of a typical Estevan lignite coal (emperical formula $CH_{0.81}O_{0.25}N_{0.01}S_{0.003}$) with a heating value of 16713 kJ/kg were gasified with air only and air/steam mixtures at near atmospheric and high pressures up to 6 MPa.

The carbon content of ash/char residues of the gasification reactions varied from 1 - 2% for air/steam reactions and was in the 16 - 53% range for reactions using air only. For all experiments the end point was clearly indicated by a rapid change in oxygen concentration in the gas samples.

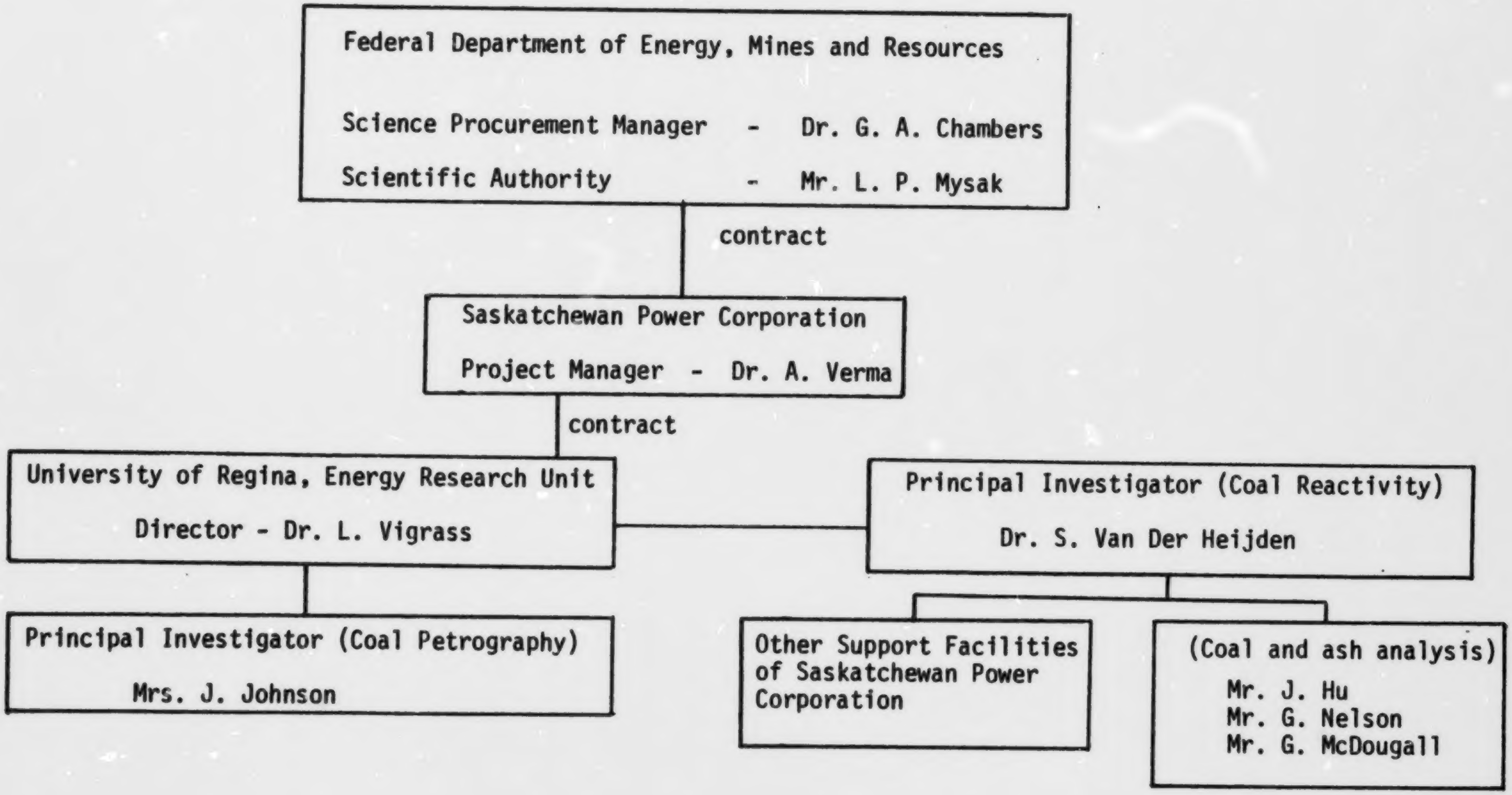
Plots of the fractional conversion of carbon as a function of time, showed high initial reaction rates as the more volatile matter in coal is gasified. The rates diminish as the carbon is being consumed. Mass balances for carbon were calculated using two methods. The first used the nitrogen in air as a tracer gas, the second used the actual measured volume of produced gas. Fair agreement between both methods is obtained for some reactions, differences are due to such factors as tar formation, leaks, and loss of carbon/char from the reactor. The use of too large linear flow rates resulted in loss of coal/char particles from the reactor in all experiments, resulting in incomplete carbon balances. The heating values for the gas samples collected during each run showed a large correlation with the methane content of the sample.

A petrological study of lignite coals and some chars seems to indicate that the potential of lignite coal lies in the assessment of the ratio: (structured huminite + liptinite)/(unstructured +inert macerals).

Several modifications to the experimental setup have been suggested to prevent loss of char/coal by other means than gasification, and to greatly reduce the time lag during high pressure experiments. Further treatment of the data collected during current work is planned in conjunction with the data to be collected during 1979-80 fiscal year.

In conclusion, there appears to be no problem in gasifying the lignite coal with air or air/steam mixtures.

PROJECT TEAM ORGANIZATION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1. Objective

Dwindling supplies of oil and natural gas have spawned renewed interest in utilization of the world's vast coal resources. There are substantial coal reserves of lignite coal in the southern part of Saskatchewan, and coal conversion is being looked at as a means to fulfill the future energy needs. The "Coronach Coal Gasification Study" recently completed in co-operation with the department of Energy Mines and Resources, shows that medium heating value gas (11.5 - 17.0 MJ/m^3) and SNG may be competitive with natural gas in the near future. In relationship to future applications, research on lignite reactivity with air, oxygen and steam should be investigated. The collection of experimental data on the behaviour of these coals not only aids in the development of expertise in the area of coal conversion but also can aid in the design and installation of future full scale gasifiers. The data will indicate which coal fields lend themselves better to gasification compared to others, and thus may have a bearing on the location of a gasification plant.

In order to provide a rapid and inexpensive optical method of analyzing lignite best suited for gasification, and, if possible, to determine how reactivity might be improved, the feasibility of using petrological techniques needs to be assessed. Studies of reflectance, spectral reflectance and maceral identification have proven to be sufficient methods of assessing the suitability of bitumineous coals for conversion. Similar methods, if applicable to lignites, would prove to be a useful technique.

Current work was carried out to achieve both the above objectives.

2.0 Introduction

Depending on end-use the four major methods of coal utilization are: gasification, combustion, liquefaction and pyrolysis. This utilization can be accomplished by the use of three reactor types: fixed bed, fluidized bed and entrained flow reactors.

The process efficiency in each case depends on the heterogeneous kinetics which control the coal char gasification with steam, carbon dioxide and hydrogen and/or char combustion with air or oxygen. A detailed understanding of heterogeneous char reaction is therefore important to coal conversion schemes.

Devolatilization of coal occurs mainly in the 400 - 900^{o}C temperature range and two stages can be considered, being rapid pyrolysis, followed by slow heterogeneous char reactions. Thermal decomposition of raw coal produces solid char plus liquid and gaseous volatile matter:

$$\text{Coal} \xrightarrow{\text{heat}} \text{Solid (Char)} + \text{Liquid (Tar)}$$
$$+ \text{Gas } (CH_4, H_2, CO, CO_2)$$

Char usually accounts for 30 - 70% by weight and consists mainly of carbon and ash, with small amounts of hydrogen, oxygen and sulfur. The exact composition and amount will depend on such factors as coal type, temperature, heating rate, pressure, time and particle size.

Char oxidation predominates during combustion, but attack on the char by steam and carbon dioxide are also important. During gasification, char combustion often provides the heat for the endothermic steam-char and carbon dioxide-char reactions. The hydrogen-char reaction produces methane. The contribution of the latter reaction is usually minor compared to pyrolysis and/or hydrogasification.

Char reactivity depends on three important characteristics of the sample: chemical structure, inorganic constituents and porosity. Chemical structure promotes active sites by providing dislocations, crystalline edges, and heterocyclic centres. Inorganic constituents promote catalytic activity and also create further activity. The pore structure fixes the total accessible surface area while controlling diffusion rates and thus the local concentration of the gaseous reactants.

2.1 Characteristics of Coal

The extent of coalification,i.e. the formation of coal from large plant masses via biochemical and geochemical processes, determines to which degree the original plant material approaches the structure of pure carbon. This coalification process is designated by the coal rank. The coal rank depends on the knowledge of a coal's proximate and ultimate analysis. Proximate analysis parallels carbonization and includes: moisture, volatile matter, ash, fixed carbon and calorific value of the sample. Ultimate analysis indicates elemental composition and includes: percent carbon, hydrogen, oxygen, nitrogen and sulfur.

The ASTM coal classification scheme is based on volatile matter for high rank coal and calorific value for low rank coals. Typically, as rank increases, percent carbon and calorific value increase while volatile matter, percent hydrogen, percent oxygen and moisture content decrease.

Since coal is a sedimentary organic rock, rank is a gross oversimplification for the highly heterogeneous nature of the coal substance.

An alternative classification emphasizing the compositional description of coal as a rock material is called petrography.

This classification is based on visual observation of reflected or transmitted light through thin coal sections. Petrographic classification is concerned with the microscopic identification of coal macerals, which are presently considered to be the fundamental constituents of coal. There are three major maceral types: vitrinite, exinite, and inertite.Vitrinite is the principal constituent of coal (60 - 90% by weight). Maceral carbon content (percent carbon by weight) increases in the order: exinite, vitrinite, inertite. For high rank coals differences in maceral composition become less noticeable.

The complexity of coal structures requires analysis in terms of the organic functional groups that are typical for each atomic species (C, H, O, N, S). The fundamental structure is polynuclear aromatic, while hydroaromatic and aliphatic structures account for most of the hydrogen. The major oxygen functional groups are, hydroxyl, carboxyl and carbonyl groups, while in lower rank coals ether, quinone, methoxyl and heterocyclic oxygen structures are also present. Sulfur and nitrogen occur as substituted aromatics or heterocyclics, such as pyridines, pyroles and thiophenes.

During carbonization, aromatic carbon is primarily responsible for char formation while tar comes from hydroaromatic carbon. Aliphatic carbon produces CH_4, CO and CO_2.

Most coals contain 10 - 30% (by weight) mineral matter. The mineral matter can be divided into four major types:

a) Alumino silicates (clays), such as kaolinite $[Al_2Si_2O_5(OH)_4]$ and illite $[KAl_3Si_3O_{10}(OH)_2]$ - 50% by volume of mineral matter

b) oxides, such as silica [SiO_2] and hematite [Fe_2O_3] - 15%

c) carbonates, such as calcite [$CaCO_3$], siderite [$FeCO_3$], dolomite [$CaCO_3 \cdot MgCO_3$] and ankerite [$2CaCO_3 \cdot MgCO_3 \cdot FeCO_3$] - 10%

d) sulfides and sulfates, such as pyrite [FeS_2] and gypsum [$CaSO_4 \cdot 2H_2O$] - 25%.

During pyrolysis, gasification, or combustion, mineral matter is transformed to ash: SiO_2 (20-60%), Al_2O_3 (10-35%), Fe_2O_3 (5-35%), CaO (1-20%), MgO (1-5%).

In addition to mineral matter, 20 - 30 trace elements are distributed through the coal structure. Concentrations of 5 - 500 μg/g are typical for trace elements, however, Ba, B, Sr, Cu, Mn, Sn and Zn often appear at the 500-1000 μg/g level.

2.2 Reactivity

The intrinsic reactivity, i.e. the number of active sites, of a char sample is primarily determined by: the concentration of carbon edges and defects; mineral matter and trace element concentrations; and oxygen and hydrogen content. The porosity and concentration of carbon edges, mineral matter and oxygen content increases for lower rank coals. This results in an increase of char reactivity as the rank of the parent coal decreases (Walker and Hippo (1975)). Mineral matter and trace elements can provide direct catalytic activity to the surface. Both chemical and physical changes are introduced in the char sample as a result of carbonization. Three major changes occur to the coal surface during heat treatment. First, oxygen and hydrogen atoms are lost. The second effect of heat treatment is conversion of mineral matter to metal oxides:

$$Al_2Si_2O_5(OH)_4 \longrightarrow Al_2O_3 + 2SiO_2 + 2H_2O$$

$$CaSO_4 \longrightarrow CaO + SO_3$$

$$CaCO_3 \longrightarrow CaO + CO_2$$

The third change due to heat treatment is thermal annealing ($T \geq$ 700-1000°C), resulting in loss of microporosity and carbon edges via cluster reorganization.

3.0 Kinetics of Gasification Reactions

Heterogeneous reactions such as reactions occurring in oxydation, steam and carbon dioxide decomposition or hydrogenation of solid carbonaceous material occur by way of a series of diffusional and chemical steps. These steps can be described as:

a) diffusion of mass (reactants and product gases) across the boundary layer surrounding the solid particle,

b) adsorption physical and/or chemical, of the reactants on the particle,

c) surface chemical reaction of the gases with the solid surfaces within the particle,

d) release of surface reaction products,

e) diffusion and mass transfer of the products to the bulk gas stream.

The heterogeneous reaction mechanism thus consists of a diffusional part, the rapidity of which depends on differences in concentration and molecular velocities near the surface and in the porous structure; and a chemical kinetic part, the rate of which depends on external and pore surface interactions.

In gas-carbon reaction kinetics both diffusional and chemical kinetic effects must be considered. The relative importance of diffusion increases with the reactivity of the carbon surface, particle diameter and small pore size. The form of the deduced rate equation, order of reaction, measured activation energy, and other kinetic phenomena become dependent on particle and pore geometrics or the degree of penetration of the reacting gases into the solid. True chemcial kinetic effects may thus be studied if all diffusional resistances are negligible.

Under "steady-state" conditions the total external diffusion rate equal the total reaction rate, and the internal diffusion rate is essentially equivalent to the reaction rate in the pore structure. The reaction rate at the external surface would then be equal to the difference between the external and internal diffusion rates.

The reaction is considered "diffusion controlled" if the resistance attributable to diffusion comprises nearly the total resistance. At negligible diffusion resistance the reaction is "kinetically controlled".

Transition of one type of rate control to another is usually indicated when a significant change of apparent activation energy occurs as obtained from an Arhenius-type plot of initial reaction rates.

Kinetically controlled rates have true activation energies in the order of 200-400 kJ, but the particular value found may not remain constant, since either the rate controlling step of the kinetic mechanism or the mechanism itself may change with temperature. Apparent activation energies of substantially diffusion controlled reactions are less than 20 KJ. All intermediate values of apparent activation energy are possible between these extremes, depending on the resistances of diffusion processes relative to those of the chemical kinetic processes.

Considerable experimental work aimed at a basic understanding of gas-carbon reaction kinetics has been reported in the literature. Excellent reviews are given by Walker et al (1959) and Laurendeau (1978).

There exists a general agreement among investigators that gas-carbon reactions follow a Langmuir-type rate equation over limited temperature ranges, and that certain of the reactants and reaction products slow down or inhibit the rate as conversion increases. The order of the reaction may vary from between zero and unity, depending on the temperature and reactant partial pressure. Reaction mechanisms consisting of elementary kinetic steps have been proposed. However, since invariably more than one mechanism can be postulated for the same rate equation, they do not necessarily validate a particular mechanism.

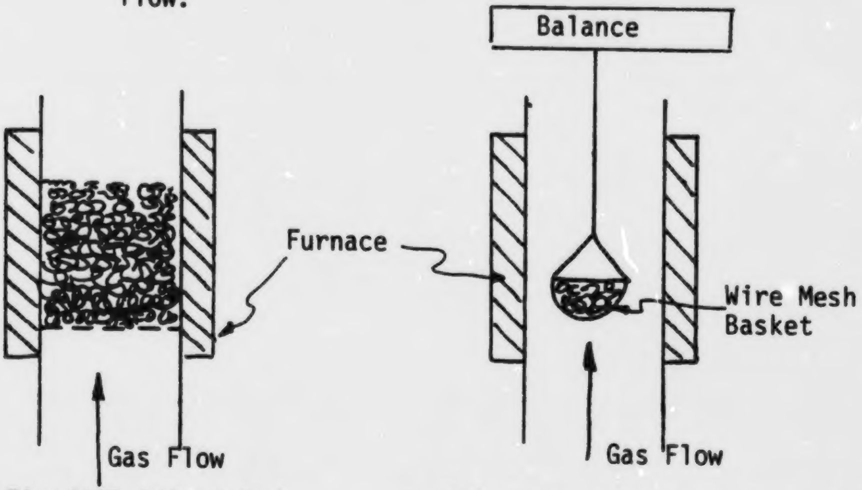
In addition to chemical composition, carbon structure, ash content and previous temperature history,all factors which influence reactivity, additional environmental factors also complicate the interpretation of gas-carbon reaction rates.

Sometimes, depending on the reactor design, temperature, and carbon sample geometry, the reaction is at an unsteady state because a change in reacting surface area. This state will exist until a particular burnoff is achieved. When this period of constant rate is attained it is kinetically more significant because it reflects a near equilibrium condition with respect to the surface area, and the results are more reproducible.

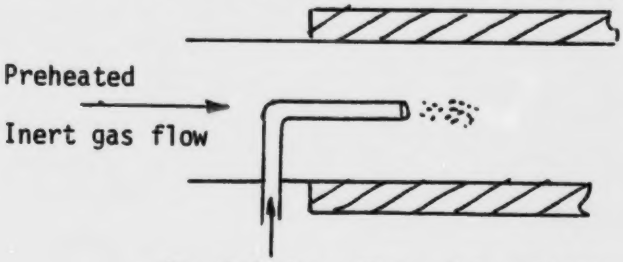
4.0 Equipment Selection

Heterogeneous kinetics can be cast into proper perspective by first considering the relevant experimental techniques:

a) fixed/fluidized bed b) thermogravimetric analysis; and c) entrained flow.


Balance
Furnace
Wire Mesh Basket
Gas Flow
Gas Flow

(a) Fixed/Fluidized Bed (b) Thermogravimetric Analysis (TGA)


Preheated
Inert gas flow
Particle/gas flow

(c) Entrained flow method

The fixed bed can be operated in either the integral (large height) or differential (small height) mode.

In the differential mode continuous sampling allows direct determination of elementary kinetic mechanisms, but experimental errors can be large due to the small product concentrations. This problem is bypassed in the integral mode, but this mode requires a plug flow or perfectly stirred reactor approximation.

The fixed bed in general allows utilization of a wider range of particle sizes, but the fluidized bed provides a nearly isothermal bed.

Kinetic data and stability can be assured in both methods by monitoring exhaust gas flow rate and species concentration.

The thermogravimetric and entrained flow methods are usually limited to global intrinsic kinetics. T.G.A. employs a continuous monitoring of the sample weight. In the entrained flow, particles can be introduced either with the preheated gas or in a central tube. Gases and solids are sampled downstream of the central jet. Isothermal conditions are rarely maintained.

Usually the reaction order is obtained by varying the reactant concentration at constant temperature, while the activation energy is calculated by varying the temperature at constant pressure.

5.0 Experimental Details

5.1 Reactors

The reactor used in the first series of experiments, conducted at near atmospheric pressure, was simpler in construction than the reactor used for the remaining high pressure experiments. The major reactor and furnace dimensions are shown schematically in figure 1. The reactor consists of a 88.9 mm O.D. - 66.6 mm I.D. seamless carbonsteel tube (Sch 160) with flanges at each end to allow connection to the coal hopper at the top, and ash/char removal via the bottom. The overall length of the reactor, excluding the coal hopper is 1.700 m. The coal was supported by a sintered stainless steel disk during gasification. The reactor was heated by a 6 kW three zone electric furnace (Lindberg model 54557). The temperature inside the reactor was measured by a single chromal-alumel thermocouple, insulated with magnesium oxide. The thermocouple was mounted in a 6.4 mm O.D. stainless steel thermowell, which in turn was mounted in the bottom cover of the reactor. Air and/or steam were introduced into the lower part of the reactor just above the bottom flange. The product gases exit from the reactor just above the furnace and were condensed, filtered, metered and sampled. The coal sample was stored in a hopper, and was dropped into the reactor via a full bore ball valve.

The major reactor and furnace dimensions for the second reactor are shown schematically in figure 2. A detailed drawing of the reactor and end closures is shown in figure 3. Plates 1 and 2 show the bottom and top closure respectively.

LOW PRESSURE GASIFICATION REACTOR

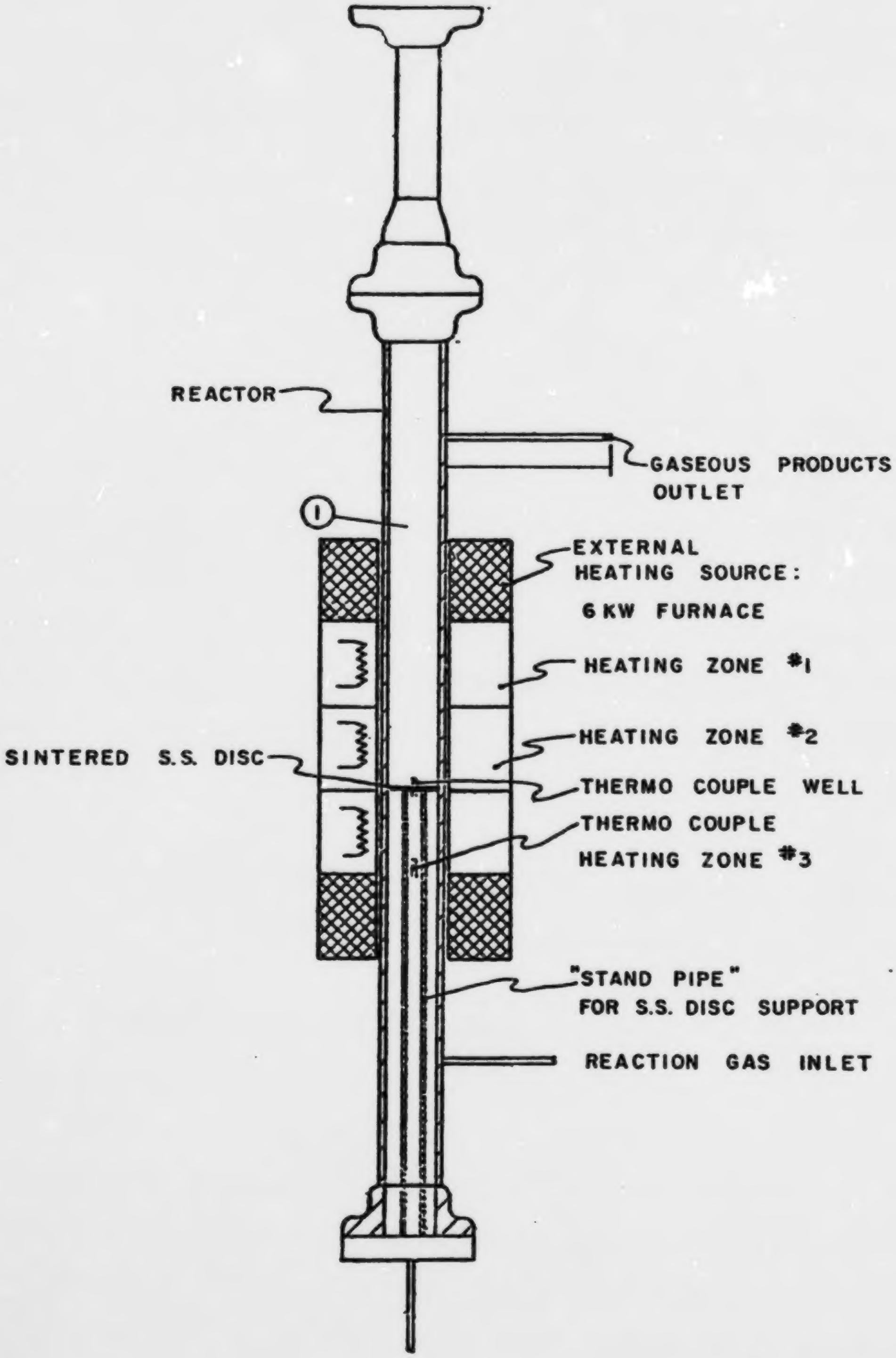

REACTOR
GASEOUS PRODUCTS OUTLET
①
EXTERNAL HEATING SOURCE:
6 KW FURNACE
HEATING ZONE #1
HEATING ZONE #2
SINTERED S.S. DISC
THERMO COUPLE WELL
THERMO COUPLE
HEATING ZONE #3
"STAND PIPE" FOR S.S. DISC SUPPORT
REACTION GAS INLET

FIGURE 1. Low Pressure Reactor

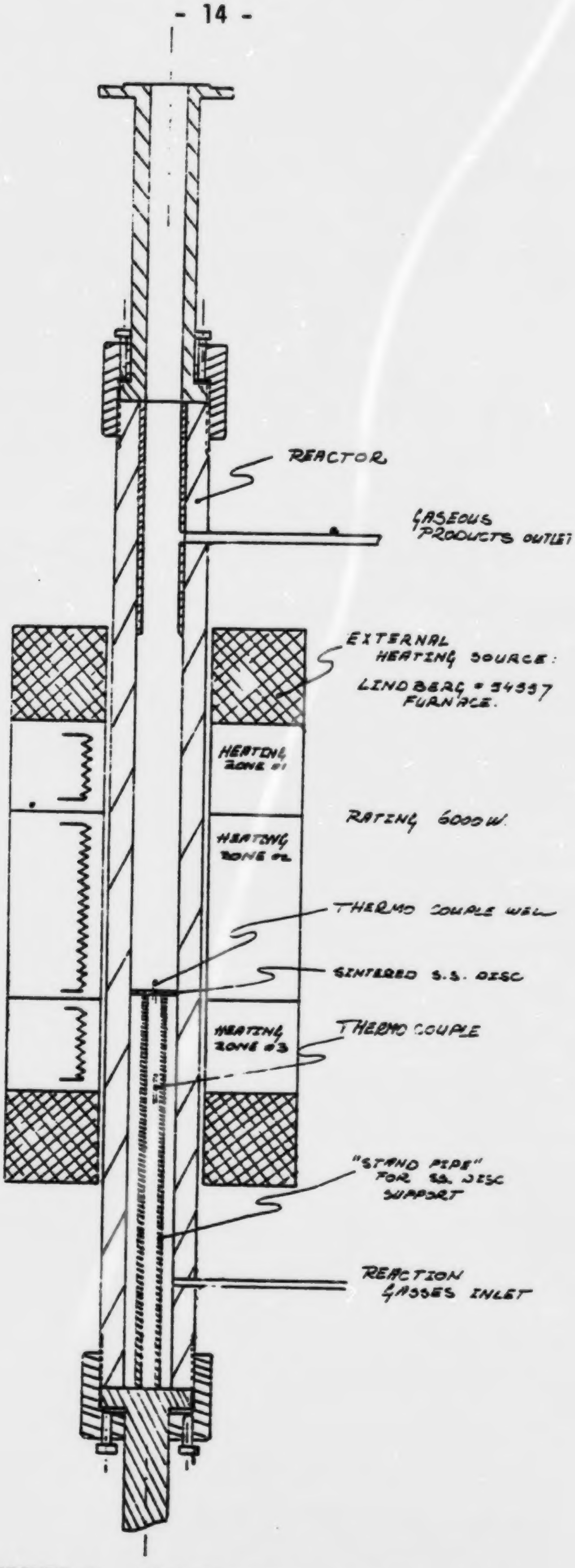

REACTOR
GASEOUS PRODUCTS OUTLET
EXTERNAL HEATING SOURCE:
LINDBERG # 54357 FURNACE.
HEATING ZONE #1
RATING 6000W.
HEATING ZONE #2
THERMO COUPLE WELL
SINTERED S.S. DISC
HEATING ZONE #3
THERMO COUPLE
"STAND PIPE" FOR SS. DISC SUPPORT
REACTION GASSES INLET

FIGURE 2. High Pressure Reactor

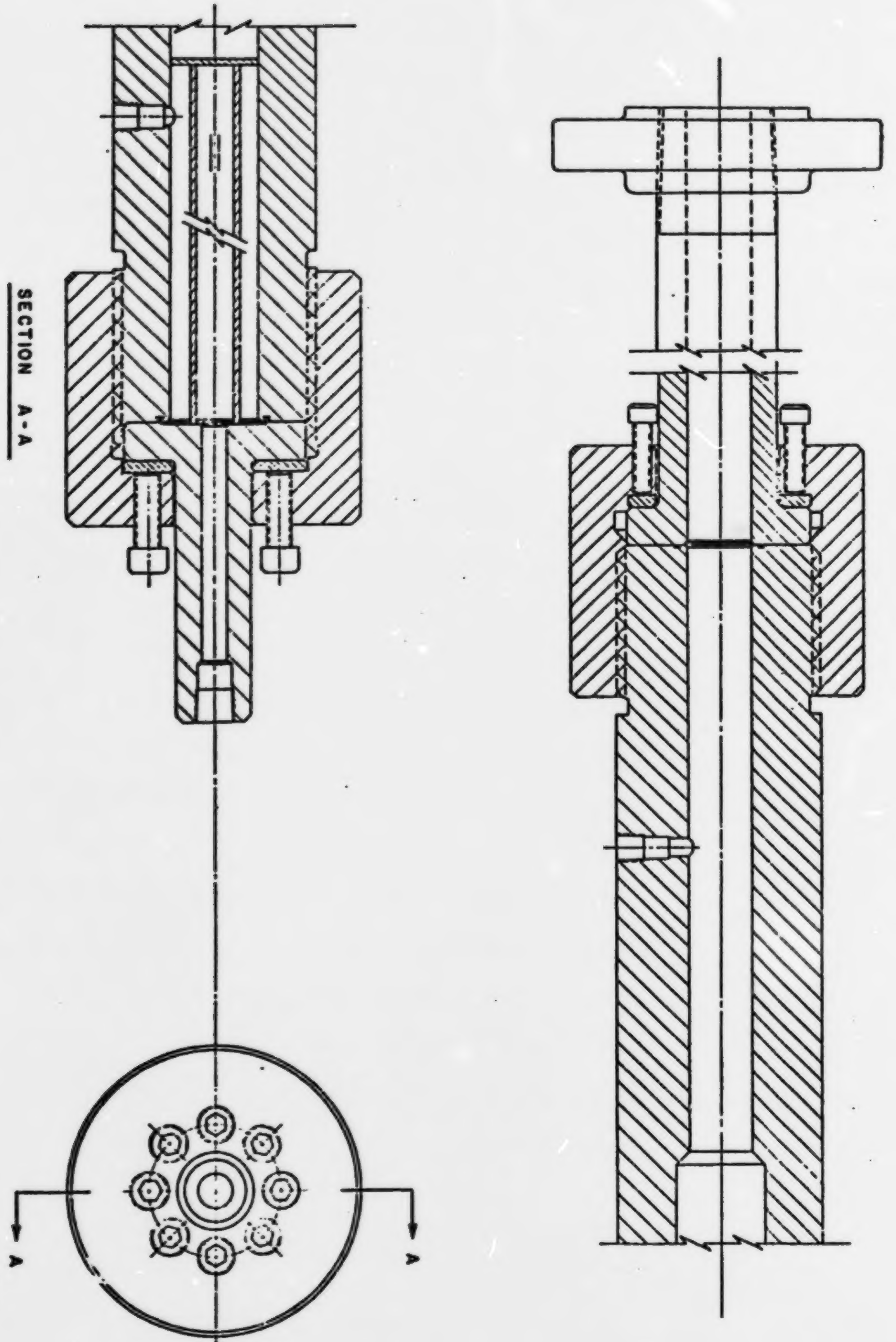

SECTION A-A
A
A

FIGURE 3. High Pressure Reactor; End Closures

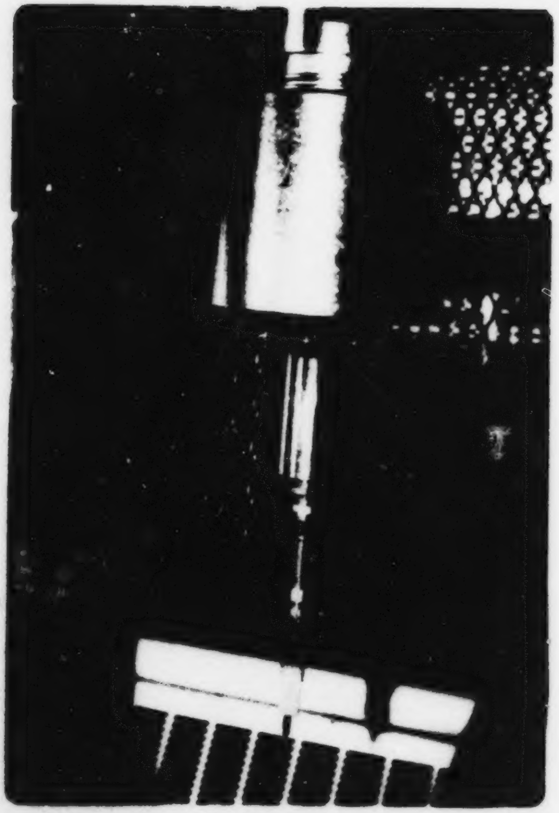


Plate 1. Bottom Closure of
High Pressure Reactor

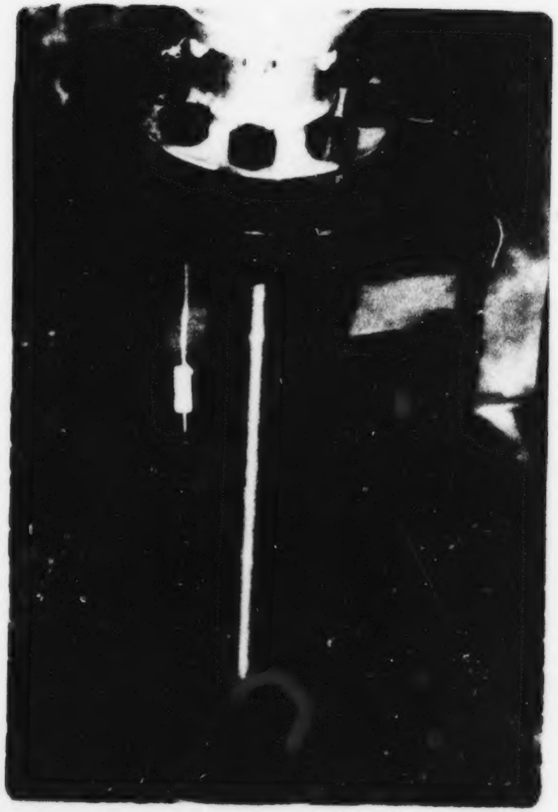


Plate 2. Top Closure of
High Pressure Reactor

The reactor body consists of a 101.6 mm O.D. - 50.8 mm I.D. Hastelloy C-276 cylinder with an overall length of 1.525 m. The two end assemblies together with the end caps are manufactured from 304 type stainless steel. The same 6 kW furnace which was used during the first series of experiments was used to heat the second reactor. A single chromal-alumel thermocouple was used to measure the temperature inside the reactor. The thermocouple was mounted in a 6.4 mm O.D. stainless steel thermowell, which was mounted in the bottom closure. The sintered stainless steel disk was replaced with a perforated carbon-steel disk. The stainless steel disk used in the first series of experiments became brittle after being heated to high temperatures, and fractured upon removal. No problems were encountered using the perforated disks. Air and/or steam were again introduced into the lower portion of the reactor just above the bottom closure. The product gases exit the reactor just above the furnace.

5.2 General Procedure

Each reactor was leak tested before each run by pressurizing with nitrogen. The reactor was then flushed and filled with helium, and externally heated to the desired operating/starting temperature. A schematic showing the experimental setup is given in figure 4, plates 3-5. The high pressure reactor was pressurized with helium just prior to introducing the coal sample into the reactor. The pressure was monitored for several minutes to ensure that no leaks had developed during the heat up period. A 500 g Estevan lignite coal sample was used for the experiment. The lignite sample was introduced into the coal hopper via the top ball valve. The top flange of this ball valve was covered with a blind flange during high pressure experiments.

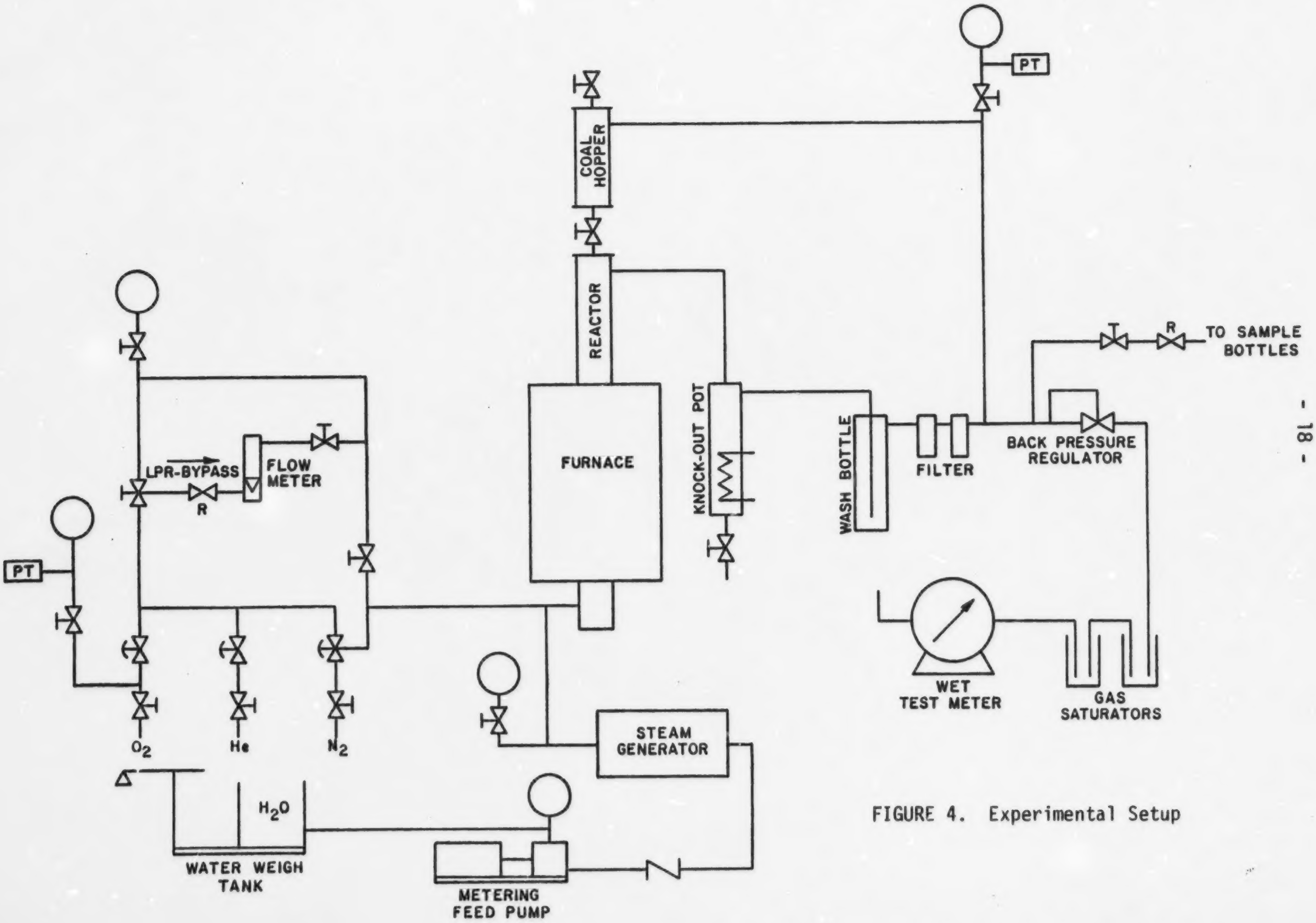

COAL HOPPER
REACTOR
FURNACE
KNOCK-OUT POT
WASH BOTTLE
FILTER
PT
BACK PRESSURE REGULATOR
R
TO SAMPLE BOTTLES
WET TEST METER
GAS SATURATORS
STEAM GENERATOR
METERING FEED PUMP
WATER WEIGH TANK
H_2O
O_2
He
N_2
PT
LPR-BYPASS
R
FLOW METER

FIGURE 4. Experimental Setup

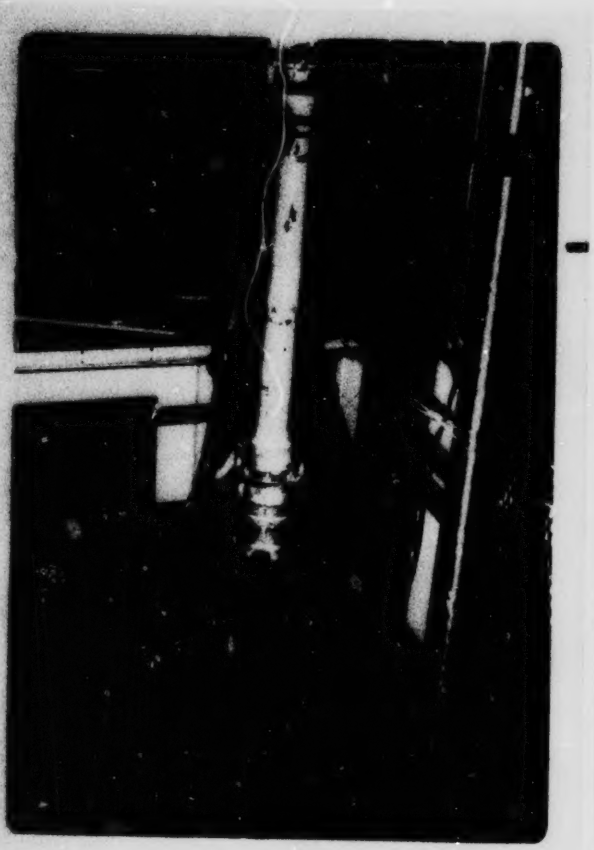


Plate 3. Coal Hopper

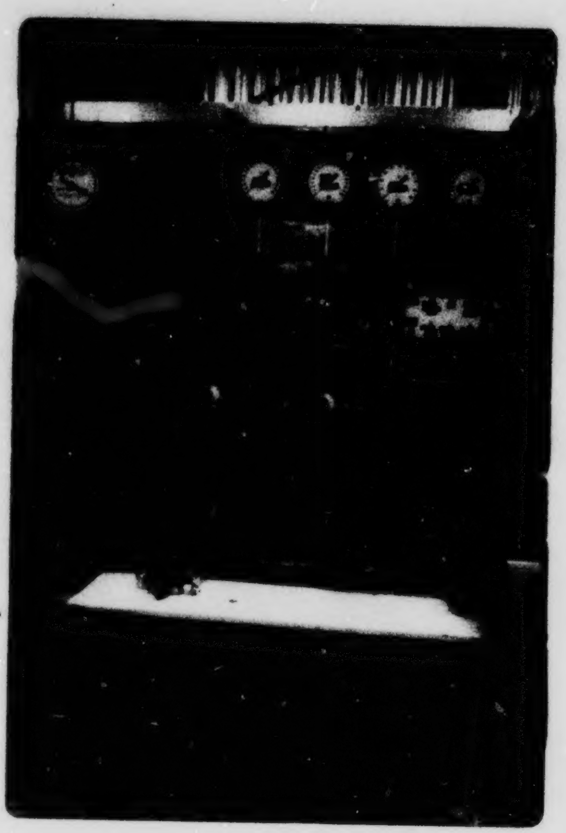


Plate 4. Control Panel

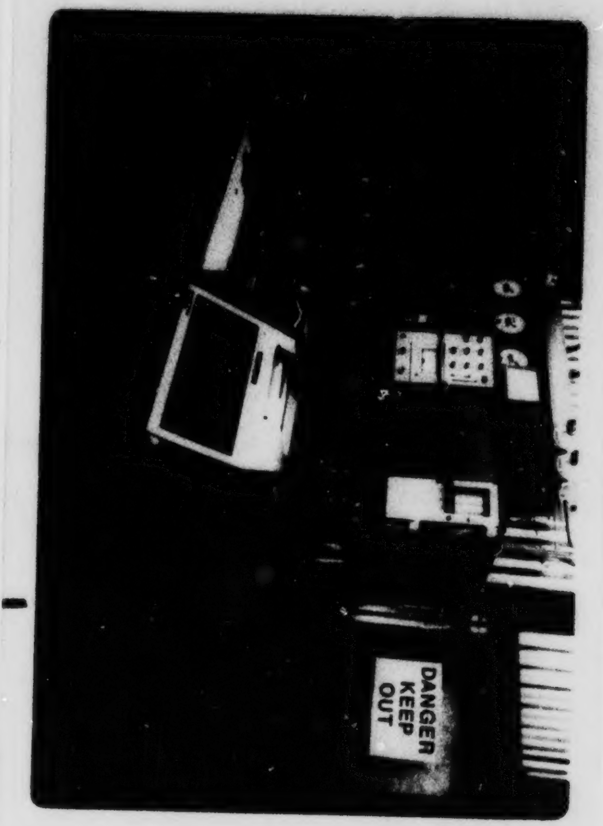

DANGER
KEEP
OUT

Plate 5. Experimental Setup

In order to reduce the loss of moisture, the coal samples, were only placed in the hopper after the reactor had reached its operating temperature, and before pressurization in the high pressure experiments. In all high pressure experiments the pressure in the coal hopper was equalized with the pressure in the reactor before dropping the coal sample into the reactor. The coal sample was dropped into the reactor via the bottom ball valve of the hopper. The ball valve was closed after the coal had been dropped into the reactor, this was verified by a drop in temperature as registered by the internal thermocouple figure 5. The pressure inside the hopper was maintained at the same level as the pressure inside the reactor to minimize leakage of the product gases along the seals of the bottom valve of the hopper. After closing the bottom valve, steam and/or air were introduced into the reactor. The air flow rate was determined by monitoring the pressure drop across the orifice of a calibrated metering valve. During the low pressure experiments a rotameter was used to obtain the air flow rates. The amount of steam consumed during an experiment was continuously monitored by weighing the water reservoir. Deionized water was taken from this reservoir and pumped via a high pressure feed pump directly into a heated stainless steel tube, which was directly connected to the lower portion of the reactor.

The product gases were continuously removed from the reactor and passed through a "knock out pot", where any liquid products and/or tars, formed during the gasification run, were condensed. The gases were then washed with water as to remove any fine char or ash particles which had not been trapped in the knock out pot.

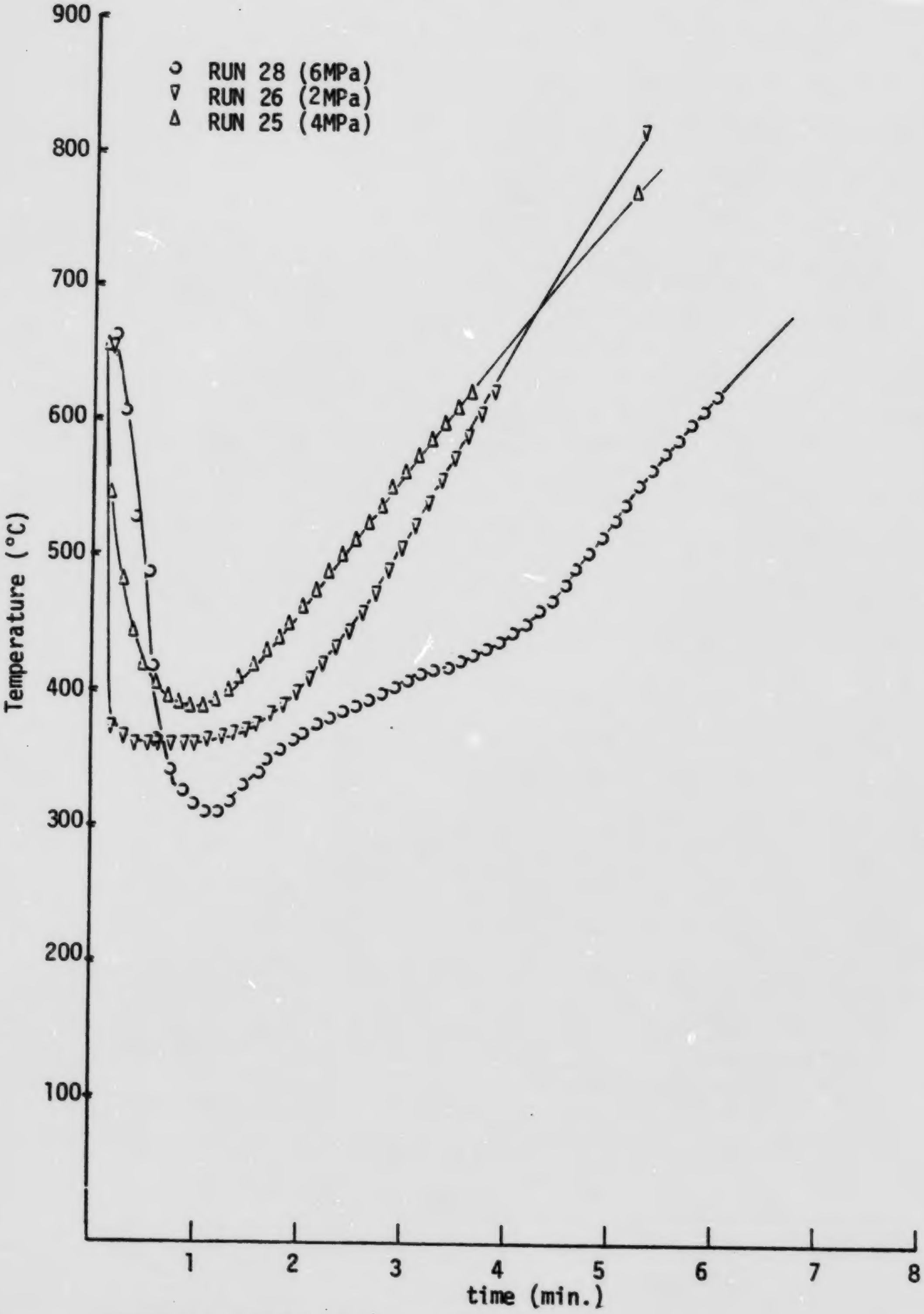


FIGURE 5 Initial Heating Rate

Gases were then depressurized and the total gas volume was measured by a wet test meter. Part of the product gas stream was collected in gas sample bottles and analyzed by gas chromatograph. After the reactions were completed, as indicated either by a drop in internal reactor temperature or the increase in oxygen concentration in the product gases, the reactor was depressurized and left to cool overnight under a slow flow of nitrogen. The char/ash remains of each experiment were removed from the reactor and analyzed for remaining carbon. The experiments lasted for 1 to 3 hours, excluding the heating up and cooling down periods, with the "typical" experiment lasting 2 hours. The number of samples withdrawn from a typical run numbered 24.

The major experimental problems were, maintaining a constant reactor pressure in the low pressure reactor, and as a direct result, a constant feed air flow rate. For the high pressure reactor operation at isothermal condition proved to be the major difficulty.

Detailed information for each individual run is given in Appendix 1.

5.3 Materials

Lignite coal samples were obtained from the Souris Valley Mine of the Utility Coal Company in Estevan. The samples collected were 3.6 m from the top of the seam.

The intrinsic properties of lignite vary between samples and these properties will all effect the reactivities of the final coal samples. In order to obtain some representative data, the samples were crushed to a certain size< 6.35 mm and well mixed.

The sample was split into two parts. One part was air dried to a moisture content of approximately 10% by weight, and was used in experiments 1-14. The most suitable particle size as determined from the first 10 experiments proved to be in the range 2.38 - 1.00 mm. Coarser particles tended to jam in the coal hopper, while smaller sized particles were carried from the reactor by the air and product gas streams. The coal for experiments 16-31 was ground to 2.36 - 1.00 mm well mixed and stored in airtight containers. The fraction below 1.00 mm was discarded.

Helium, compressed air and nitrogen were obtained from local suppliers.

5.4 Analysis

Ultimate and proximate analysis were performed on selected feed samples (Table 1, 2).The samples used for experiments 16 through 31 proved to be quite uniform with average values of 26.7%, 13.0%, 30.8% and 29.5% for moisture, ash, volatile matter and fixed carbon respectively.

Proximate analysis were performed on all residues in order to determine the amount of ash and fixed carbon left in the char/ash samples. The results are shown in tables 3 - 5.

The product gases obtained during the atmospheric pressure experiments 12 through 20, were analyzed for CH_4, CO, H_2, N_2 and O_2. The analysis were performed using a 1.8 m x 5 mm molesieve column. Since CO_2 absorbs on this column, the CO_2 content was calculated as $(\frac{21.9}{78.1} \times N_2) - (O_2 + \frac{1}{2} CO)$. The gas compositions are listed in appendix 2.

The product gas samples collected from the high pressure reactions were analyzed for CO_2, CO, OH_4, C_2H_6, H_2, N_2, and O_2, using a Fisher model 1200 gas partitioner.

A typical chromatogram is shown in figure 6.

Table 1. Ultimate Analysis of Estevan Lignite Coal Used in This Study

Run #	Carbon Wt.%	Hydrogen Wt.%	Nitrogen Wt.%	Sulfur Wt.%	Ash Wt.%	Oxygen* Wt.%
12	57.5	3.7	0.04	0.71	18.2	19.9
16	55.3	3.5	0.82	0.41	21.5	18.5
19	56.9	3.9	0.75	0.42	19.2	18.8
21	61.4	3.8	0.93	N.D.	17.2	16.7 **
26	54.4	4.3	0.23	N.D.	20.4	20.7 **
27	57.2	4.5	0.82	0.33	17.2	20.0
31	58.6	3.7	0.51	0.31	17.1	19.8

* Oxygen by difference, calculated as 100 - (%C + %H + %N + %S + % Ash)

** Includes sulfur

The average composition for the Estevan Lignite Coal based on the above analysis is:

$$CH_{0.81}O_{0.25}N_{0.01}S_{0.003}$$

Table 2. Proximate Analysis of Estevan Lignite Coal Used in This Study

Run #	As received basis				Moisture free basis		
	Moisture Wt.%	Ash Wt.%	V.M. Wt.%	F.C. Wt.%	Ash Wt.%	V.M. Wt.%	F.C. Wt.%
12	9.4*	16.5	35.4	38.7	18.2	39.1	42.7
16	21.6	16.9	28.6	33.0	21.5	36.4	42.0
19	27.7	13.9	28.2	30.2	19.2	38.9	41.9
21	26.9	12.6	31.0	29.5	17.2	42.3	40.5
27	26.0	12.7	32.0	29.3	17.2	43.2	39.6
31	26.2	12.0	31.8	30.0	16.3	43.1	40.7

* The sample used in runs 12, 13 and 14 were air dried to a moisture content of approximately 10%.

V.M. = Volatile matter

F.C. = Fixed carbon, determined as 100 - (moisture + ash + V.M.)

Table 3.

Proximate Analysis of Ash/Char Remains After Gasification

Run #	As determined basis				
	Moisture %	Ash%	V.M.%	F.C.%	
12	0.7	74.6	8.1	16.6	
13	1.3	64.6	16.5	17.6	
14	6.4	79.8	10.5	3.3	
15	0.4	93.9	5.7	0	
16	1.5	42.9	23.1	32.5	
17	8.6	25.4	30.9	35.1	
18	0.3	91.4	8.3	0	
19	0.3	95.7	4.1	0	
20	0.3	72.6	6.6	20.5	
21	0.1	95.8	4.2	0	
22	0.3	97.4	2.3	0	
23	0.4	97.0	2.6	0	
24	0.5	99.3	0.2	0	
25	0.5	98.7	0.9	0	
26	0.5	98.4	1.1	0	
27	0.6	94.2	5.2	0	
27 *	0.5	30.9	7.3	61.3	Char
28	0.5	96.7	2.9	0	
29	0.5	97.2	2.4	0	
30 **	0	26.2	4.7	69.1	Char
31	0.4	92.4	5.5	1.7	

* The ash in this aborted high pressure run was fused into a thin wafer and could therefore be easily separated from the remaining char.

** Char remaining after pyrolysis at 2 MPa and 800°C.

V.M. = Volatile matter
F.C. = Fixed Carbon, determined as 100 - (moisture + ash + V.M.)

Table 4. Carbon and hydrogen content of char/ash remains after gasification

Run#	Carbon Wt.%	Hydrogen Wt.%	Run #	Carbon Wt.%	Hydrogen Wt.%
12	26.3	0.45	21	1.95	0.20
13	32.3	1.3	22	1.11	0.17
14	16.0	0.95	23	2.28	0.21
15	4.89	0.38	24	0.84	0.34
16	45.7	2.4	25	0.74	0.15
17	53.2	3.5	26	0.72	0.16
18	6.44	0.34	27	4.65	0.46
19	1.73	0.21	27*	62.5	1.3
20	30.4	0.38	28	1.74	0.15
			29	1.32	0.18
			30**	59.2	1.2
			31	5.73	0.32

* The ash in this aborted high pressure run was fused into a thin wafer, and could therefore be easily spearated from the remaining char.

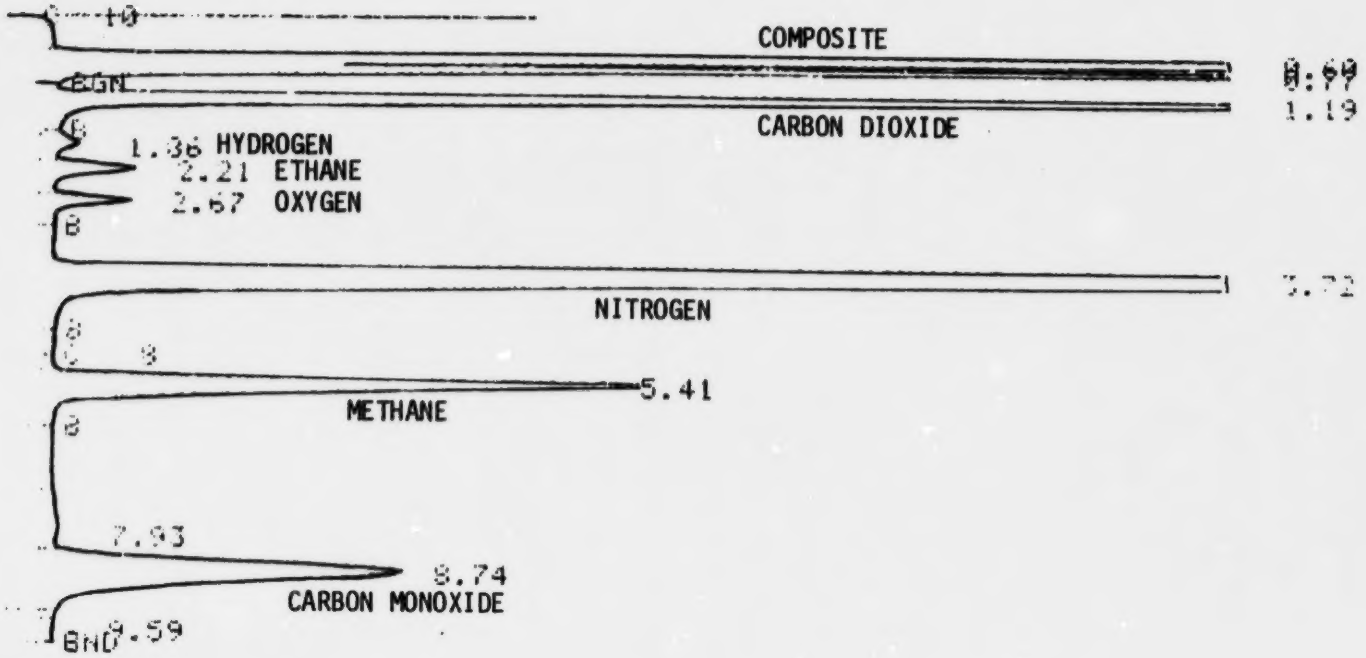
** Char remaining after pyrolysis at 2 MPa and 800°C.

Table 5.

Ash Analysis of Some Gasification Remains

Weight Percent

Constituent	Sample				
	14	18	23	25	28
SiO_2	27.36	39.54	44.46	41.04	38.31
Al_2O_3	22.66	25.95	29.66	26.37	26.20
Fe_2O_3	22.85	8.87	5.36	5.57	6.19
TiO_2	0.36	0.50	0.88	0.89	0.62
P_2O_5	0.18	0.07	0.06	0.17	0.26
CaO	12.94	12.06	12.06	11.40	11.86
MgO	2.51	2.25	2.89	2.14	2.58
SO_3	3.94	3.00	1.31	1.45	1.86



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INST  1  METH    2  FILE   27

RUN      8  CARBON STEAM AIR  6MPA  R29   14 :  5.8   1 / 26 / 79
```

FIGURE 6. Typical Chromatogram

6.0 Results and Discussion

6.1 Product Gas Composition

The product gas compositions, obtained for each sample collected during the gasification experiments, are given in Appendix 2. For some experimental runs, graphical representations of the gas compositions as a function of time are given in figures 7 - 12. The data are divided over two graphs. The first shows the variation in concentration for Nitrogen, Hydrogen, Carbon Monoxide and Carbon Dixoide as the reaction progresses. The second graph shows the concentrations for Oxygen, Methane and Ethane, together with the heating value, calculated for each composition. The sharp and rapid increase in oxygen concentration clearly indicates when all carbon has been gasified. The increase in oxygen concentration generally coincides with a decrease in temperature and an increase in the nitrogen concentration, but these effects are less pronounced.

Large fluctuations were observed in the hydrogen concentrations for individual experiments. These variations are believed to be caused by the dilution effect which gives rise to very low concentrations of the product gases in the first couple of samples taken during high pressure experiments. This dilution effect arises from the fact that before the start of each high pressure experiment the reactor is pressurized with helium. The first product gases therefore are being diluted by a large volume of helium and this dilution factor increases with increasing pressure. This effect is worsened by the low sensitivity of a thermal conductivity detector for hydrogen, using helium as a carrier gas. The response factor of the detector was found to be 1/50th that of nitrogen, using helium as a carrier gas.

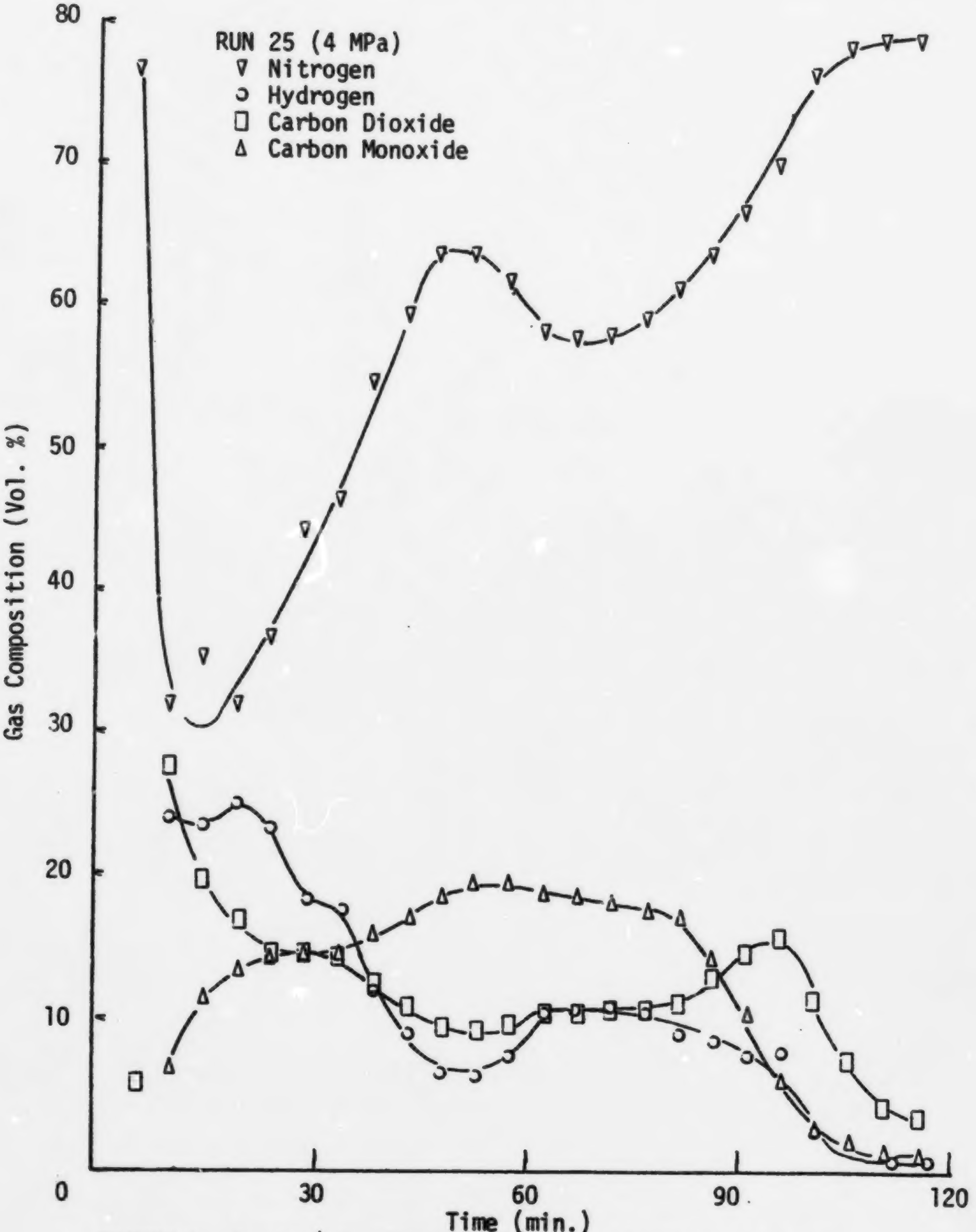

FIGURE 7. Product Gas Composition as a Function of Time

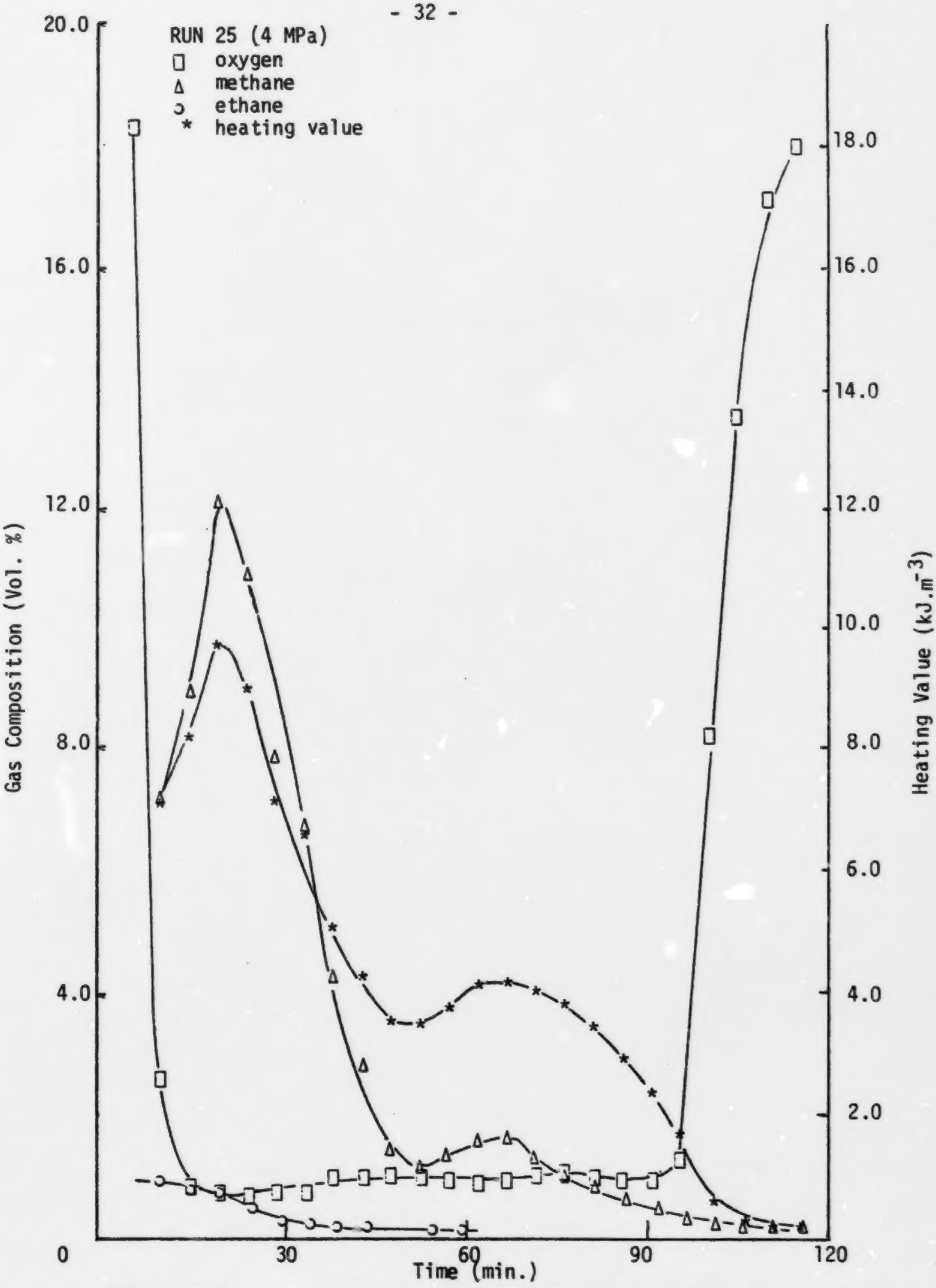

FIGURE 8. Product Gas Composition as a Function of Time

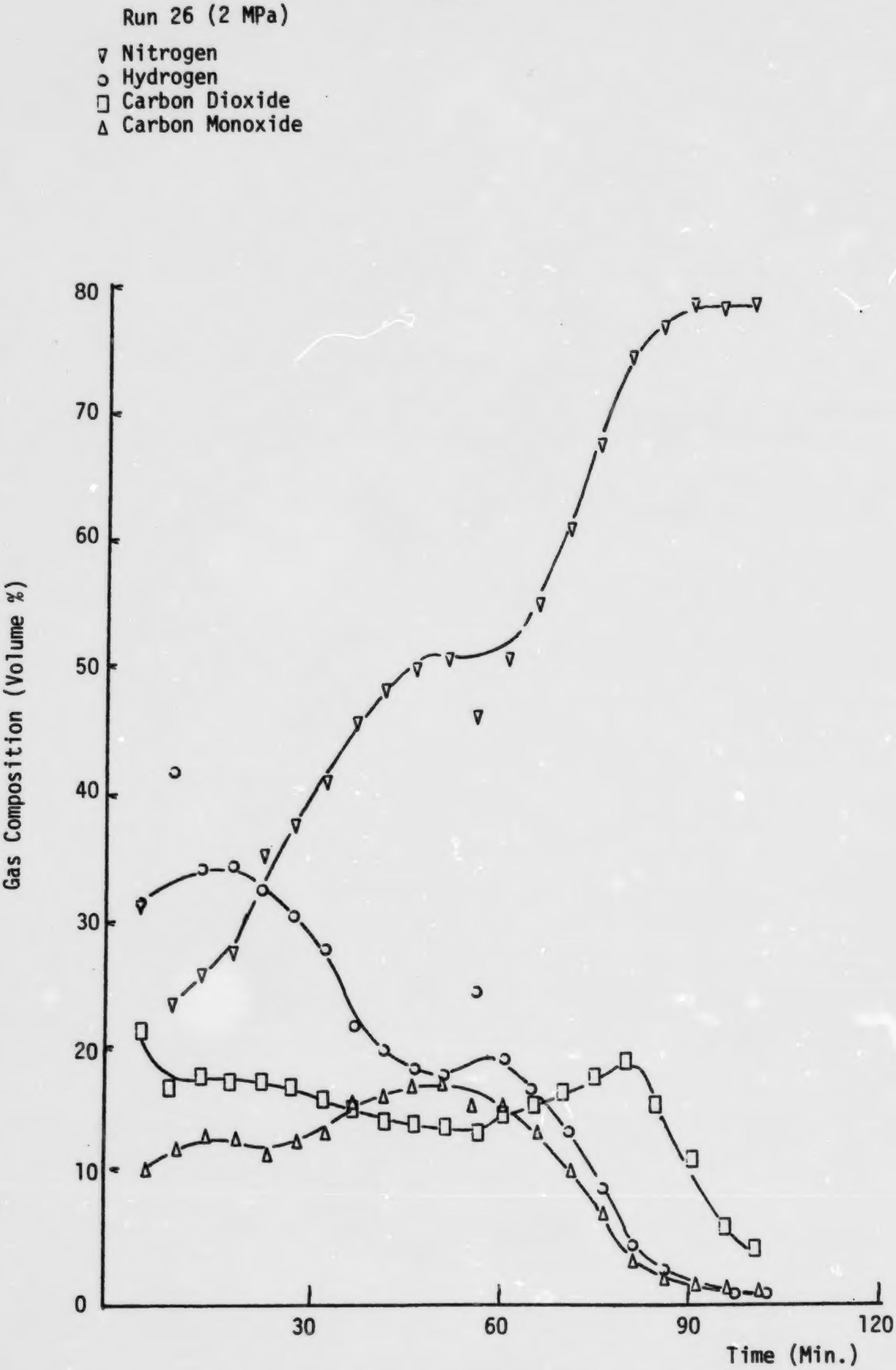

Figure 9. Product gas composition as a function of time.

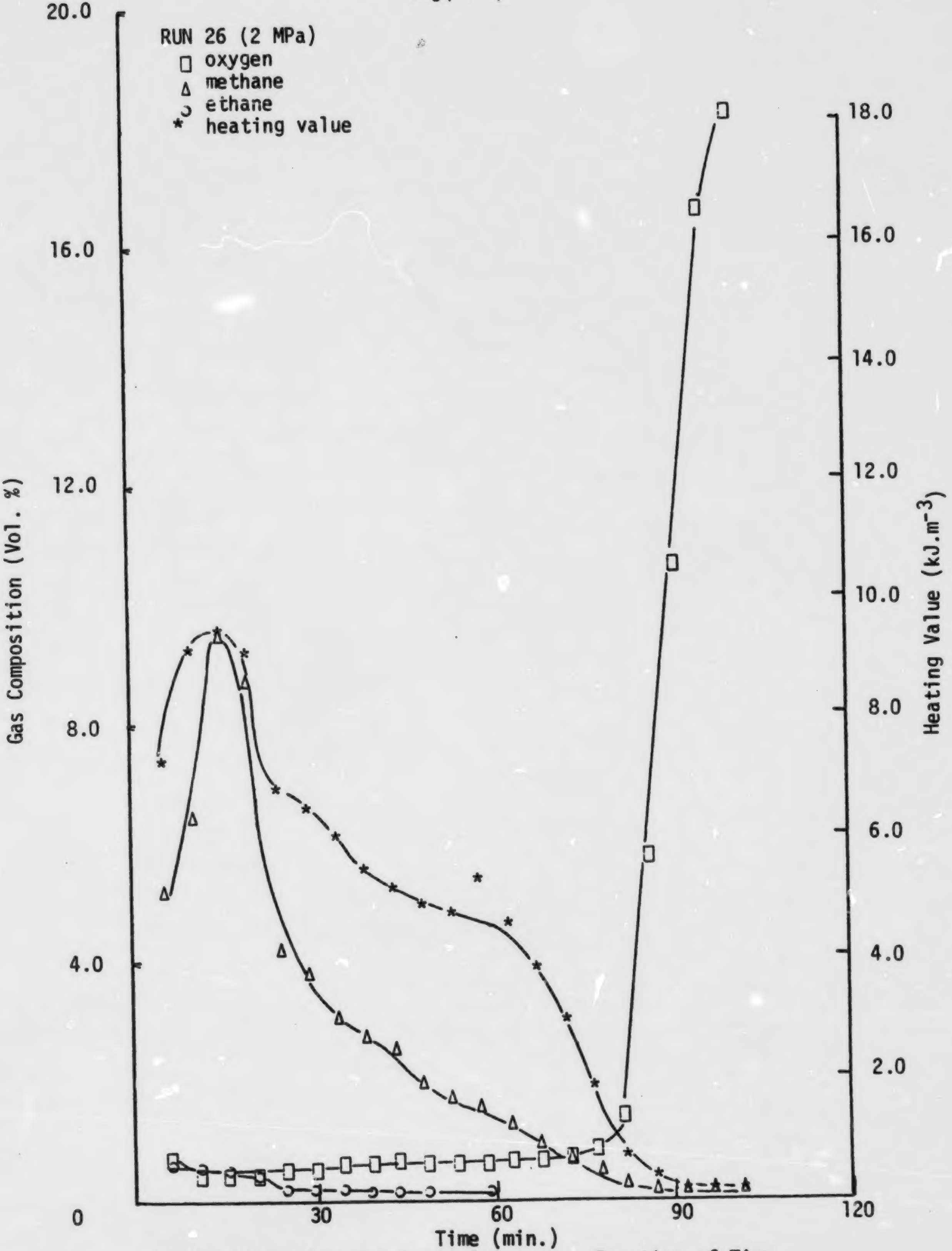

FIGURE 10.Product Gas Composition as a Function of Time

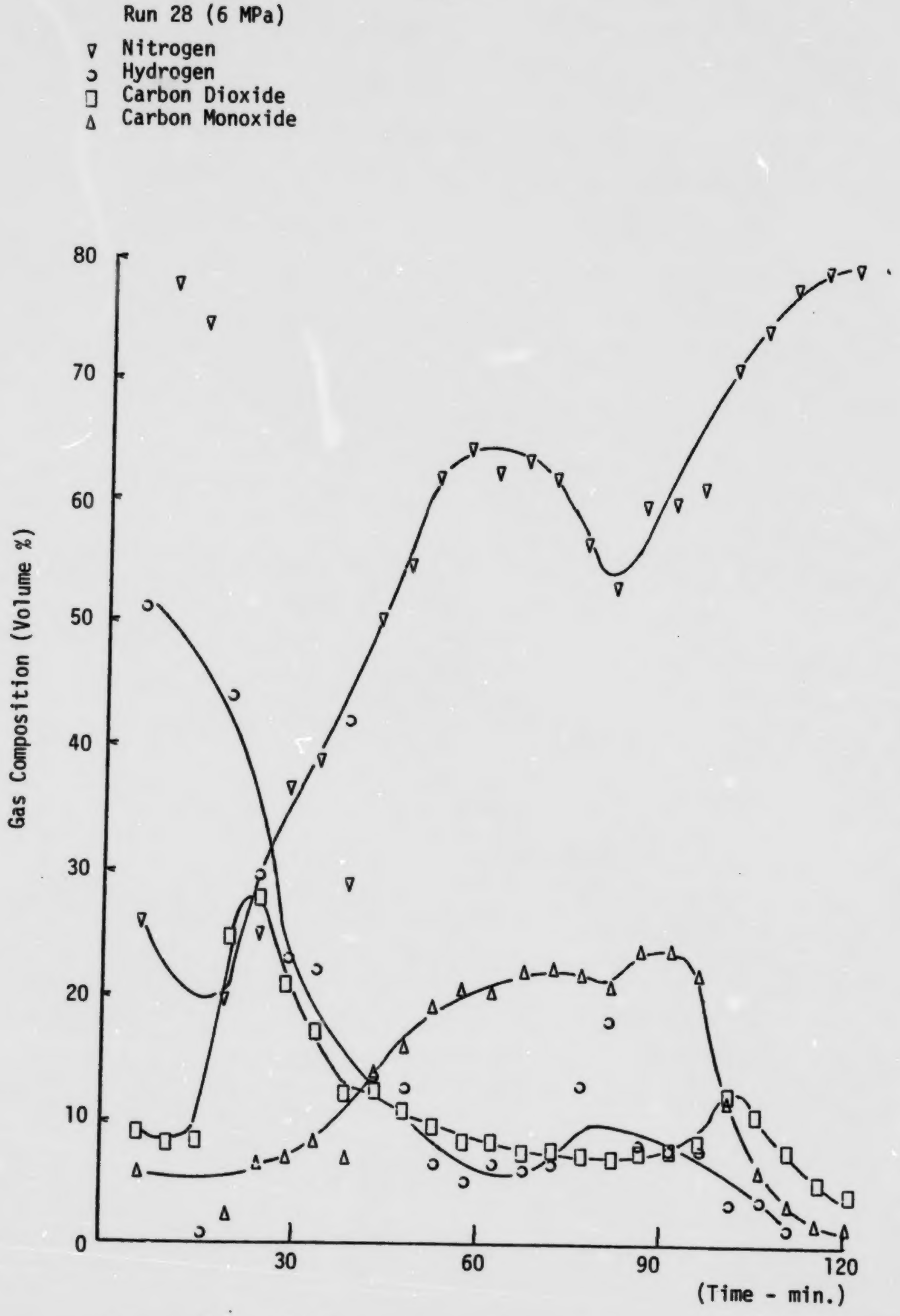

Figure 11. Product gas composition as a function of time.

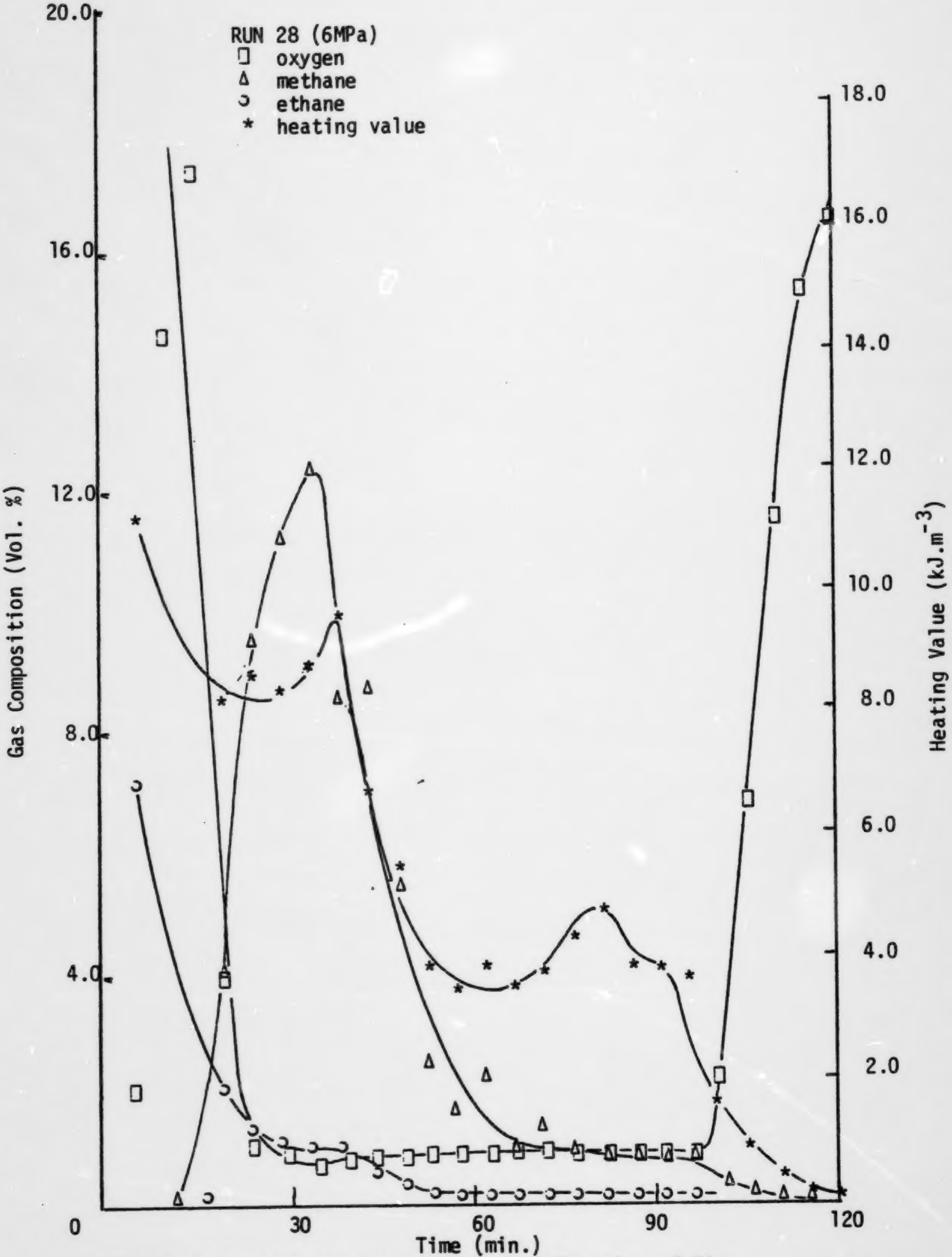

FIGURE 12. Product Gas Composition as a Function of Time

The use of helium as a carrier gas is usually not recommended for the determination of hydrogen. The sensitivity for the detection of hydrogen in helium as a carrier gas is low because of the small difference in the thermal conductivities of the two gases (He = 140.58 J/cm.sec/^{0}C; H_2 = 163.18 J/cm.sec/^{0}C). In addition, the determination of hydrogen may be complicated by anomalous cell response to hydrogen-helium mixtures. The use of nitrogen as a carrier gas is excluded by the fact that the samples have to be analyzed for nitrogen content. The use of argon as a carrier gas, gives exceptional sensitivity to the detection of hydrogen, however the sensitivity for the remaining components in the product gases is greatly reduced, in addition the chromatographic response for carbon dioxide is in the reverse direction to that of the remaining gaseous components in the sample.

Fluctuations of the other gaseous components in the product gas sample are believed to result directly from fluctuations in the hydrogen concentration. A typical chromatogram is shown in figure 6. The composition for the sample shown is : Hydrogen 12.5%, Carbon Dioxide 14.5%, Ethane 0.7%, Oxygen 0.6%, Nitrogen 48.6%, Methane 11.8% and Carbon Monoxide 11.3%, and clearly portrays the low sensitivity towards hydrogen.

The low pressure reactions showed that methane was only formed during the first 10 - 25 minutes of the reaction, when using air only. The methane formed here resulted mainly from the pyrolysis of the lignite coal to char during the early stages of the reaction. When steam/air mixtures were used (experiment 18 and 19) the time span of methane production was extended to 30 - 45 minutes after start of the reaction.

Methane was formed during the entire duration of the reaction in high pressure experiments. The maximum methane concentration observed for a single sample during the high pressure experiments was 15.8%, while the maximum observed during the low pressure experiments reached 8.0% CH_4. The total number of moles of methane gas produced during the low pressure experiments varied from 0.2 to 0.8 moles, while the total for the high pressure experiments ranged from 0.7 to 2.0 moles.

High pressure experiments showed a large time lag, ie. time needed for the product gas to reach the sampling point in the system. This time delay is caused by the large volume of gas present in the experimental setup, and this volume increases with increasing pressure. It is also this large volume of gas that is responsible for the dilution effect as discussed earlier. A way of reducing these effects is discussed under recommendations.

6.2 Carbon Conversion

The carbon balances were calculated by two different methods. The first method was based on the supplied air volume. The assumption was made that nitrogen behaves as an inert gas and does not react with the coal, and that the amount of nitrogen contributed by the coal is negligible. The total number of moles of nitrogen introduced into the reactor, therefore must equal the number of moles of nitrogen in the product gas over the same time period, the nitrogen thus acts as a "tracer" gas. The use of Argon as a tracer gas is not possible since Argon and oxygen are not separated during the chromatographic analysis of the product gases, thus making it impossible to obtain a correct value for the oxygen content in the gas sample. The total number of moles for each gaseous component in the product gas was calculated by assuming, that the average product gas composition during a certain time interval was equal to the midpoint between the concentrations of each component as determined at the beginning and the end of that time interval. The time intervals were chosen to be the time durations between sampling points. Since the total volume of air introduced over the time interval was known, the number of moles of nitrogen in the averaged gas sample was equated to the amount of nitrogen in the air volume, and the component/nitrogen ratio's were used to obtain the corresponding number of moles for each component.

The second method used the same averaged product gas composition values, but the number of moles for each gaseous component was calculated using the volume of gas produced as measured by a wet test meter, over the corresponding time interval between sampling points. Table 6 gives a comparison between the measured gas volumes and those calculated on the basis of supplied air volume.

The agreement between calculated and observed volume varies from good for run 24 to unacceptable for run 29. Discrepancies arise from factors such as:

a) inaccuracies in measurement of the supplied air flow rate. (The air flow rate is calculated from the pressure drop across the orifice of a calibrated metering valve.)

b) removal of gas samples from the system for analysis, before measurement by the wet test meter.

c) leakage of product gas from the system.

The last two factors (b and c) will result in carbon balances calculated on a produced gas volume basis to be less than those calculated on a supplied air basis. Inaccuracies in flow measurement can result in the carbon balances either being too high or too low, when they are calculated on the basis of supplied air volume. Even though a slight

Table 6. Comparison between measured gas volumes and those calculated on the basis of supplied air volume

	Run 24		Run 26		Run 29	
	Accumulative volumes * in m^3					
Sample No.	Calc.	Measured	Calc.	Measured	Calc.	Measured
1	0.134	0.136	0.088	0.083	0.105	0.116
2	0.294	0.295	0.188	0.181	0.193	0.163
3	0.462	0.434	0.301	0.283	0.383	0.198
4	0.612	0.564	0.404	0.360	0.502	0.229
5	0.739	0.686	0.492	0.432	0.599	0.262
6	0.854	0.798	0.568	0.499	0.677	0.298
7	0.965	0.898	0.638	0.559	0.740	0.334
8	1.067	0.983	0.702	0.617	0.799	0.373
9	1.157	1.072	0.761	0.674	0.852	0.410
10	1.236	1.166	0.871	0.731	0.900	0.453
11	1.313	1.258	0.872	0.789	0.943	0.492
12	1.389	1.349	0.929	0.847	1.006	0.539
13	1.442	1.439	0.986	0.900	1.026	0.586
14	1.541	1.530	1.638	0.947	1.070	0.634
15	1.617	1.575	1.086	0.991	1.106	0.684
16			1.129	1.028	1.147	0.731
17			1.168	1.094	1.189	0.780
18			1.205	1.106	1.232	0.830
19			1.240	1.147	1.274	0.889
20			1.275	1.187	1.317	0.944
21			1.310	1.228	1.361	1.013
22					1.451	1.148
23					1.550	1.243
24					1.598	1.280

* at 15°C and 101.3 kPa

error in the flow rate calculation would offset the amount of nitrogen only by a constant amount, this holds no longer true for the overall gas volume since the amount of nitrogen differs in each gas sample. The accumulative total number of moles for each reaction using both methods of calculation, are given in appendix 3.

Using the accumulated number of moles, the total amount of carbon consumed was calculated. Curves for the fractional conversion of carbon as a function of time are shown in figures 13 - 21. The fractional conversion is defined as:

$$X = 1 - \frac{\text{moles carbon at time t}}{\text{moles carbon initially}}$$

The conversion curves were obtained using both methods of calculation as outlined above. The curves show high initial reaction rates as the more volatile matter in the coal is gasified, followed by a much slower reaction regime where the rate slowly diminishes as the coal is consumed. The total carbon conversion data are given in table 9. The inability to obtain total conversion is mainly due to such factors as:

a) The formation of tars and other non-gaseous hydrocarbon products,

b) inaccuracies in flow measurements,

c) errors in product gas analysis,

d) and loss of char/ash from the reactor.

The latter is believed to be the major source of "lost" carbon. The amount of ash obtained for each experimental run (Table 10 was approximately 60 - 80% of the amount of ash which would be recovered on the basis of the proximate analysis of the original coal sample.

Table 7. Total Amount of Gaseous Components Produced During Each Run

Based on produced gas volume

Run #	Moles							Type
	CO_2	H_2	C_2H_6	O_2	N_2	CH_4	CO	
12*	3.47	19.37	N.D.	0.75	33.05	0.36	10.21	AC∿45 kPa
13*	6.39	18.53	N.D.	3.93	50.11	0.40	7.55	AC∿45 kPa
14*	4.28	6.21	N.D.	5.03	59.30	0.66	15.07	AC∿45 kPa
15*	3.27	13.46	N.D.	3.07	35.05	0.16	6.97	AC∿45 kPa
16*	4.93	2.46	N.D.	2.79	36.40	0.23	4.99	AC∿45 kPa
17*	4.79	4.01	N.D.	1.58	38.78	0.50	9.03	AC∿45 kPa
18*	3.95	16.76	N.D.	3.26	33.41	0.47	4.31	ASC∿45 kPa
19*	0.87	17.46	N.D.	0.93	16.19	0.77	9.27	ASC∿45 kPa
20*	3.29	4.00	N.D.	1.27	31.25	0.34	8.40	AC∿45 kPa
21	4.42	10.68	0.11	1.07	20.12	1.31	6.77	ASC 2 MPa
22	5.64	8.49	0.07	0.88	19.12	1.49	5.72	ASC 2 MPa
23	3.10	4.54	0.03	0.82	10.71	0.71	2.03	ASC 2 MPa
24	5.23	7.83	0.89	3.79	36.74	1.55	8.50	ASC 4 MPa
25	5.57	4.86	0.08	1.69	25.79	1.43	5.49	ASC 4 MPa
26	7.67	11.38	0.08	0.95	22.85	1.74	5.48	ASC 2 MPa
28	4.88	5.69	0.26	2.42	28.87	1.34	5.72	ASC 6 MPa
29	7.53	4.87	0.15	0.64	28.22	1.95	8.33	ASC 6 MPa
30	1.52	5.04	0.09	0.05	--	0.97	0.47	Pyrol 2 MPa

* CO_2 calculated as $(0.2805 \times N_2) - (O_2 + 0.5 \times CO)$

AC∿45 kPa = air-carbon reaction at 45 kPa pressure
ASC 2 MPa = air-steam-carbon reaction at 2 MPa pressure
Pyrol 2 MPa = Pyrolysis at 2 MPa pressure

Table 8. Total Amount of Gaseous Components Produced During Each Run

Based on supplied air volume

Run #				Moles				Type
	CO_2	H_2	C_2H_6	O_2	N_2	CH_4	CO	
12*	4.32	67.18	N.D.	1.45	48.36	0.93	16.20	AC∿45 kPa
13*	7.68	38.31	N.D.	4.88	66.50	0.68	12.33	AC∿45 kPa
14*	4.91	9.02	N.D.	5.76	68.11	0.91	17.41	AC∿45 kPa
15*	4.00	40.96	N.D.	3.62	46.35	0.52	10.76	AC∿45 kPa
16*	4.76	6.41	N.D.	2.66	35.07	0.25	4.84	AC∿45 kPa
17*	4.45	3.89	N.D.	1.49	36.03	0.46	8.34	AC∿45 kPa
18*	3.67	14.99	N.D.	3.02	30.46	0.39	3.71	ASC∿45 kPa
19*	0.89	16.36	N.D.	0.97	15.57	0.75	8.57	ASC∿45 kPa
20*	3.20	4.59	N.D.	1.25	30.56	0.38	8.23	AC 45 kPa
21	3.38	8.43	0.08	0.81	15.41	0.96	5.15	ASC 2 MPa
22	6.06	9.11	0.05	0.82	22.37	1.41	7.11	ASC 2 MPa
23	9.30	14.53	0.15	1.38	26.51	2.63	6.30	ASC 2 MPa
24	5.86	9.12	0.11	3.68	38.20	1.82	9.59	ASC 4 MPa
25	6.95	6.65	0.11	1.71	29.54	2.16	6.77	ASC 4 MPa
26	8.68	13.17	0.11	0.92	24.35	2.06	6.12	ASC 2 MPa
28	7.22	10.87	0.68	2.35	30.80	2.23	6.45	ASC 6 MPa
29	13.83	9.20	0.40	0.94	30.80	3.87	8.55	ASC 6 MPa
30	7.56	20.80	0.33	0.11	--	2.82	1.55	Pyrol 2 MPa

* CO_2 calculated as $(0.2805 \times N_2) - (O_2 + 0.5 \times CO)$

AC∿45 kPa = air-carbon at 45 kPa pressure
ASC 2 MPa = air-steam-carbon at 2 MPa pressure
Pyrol 2 MPa = Pyrolysis at 2 MPa pressure

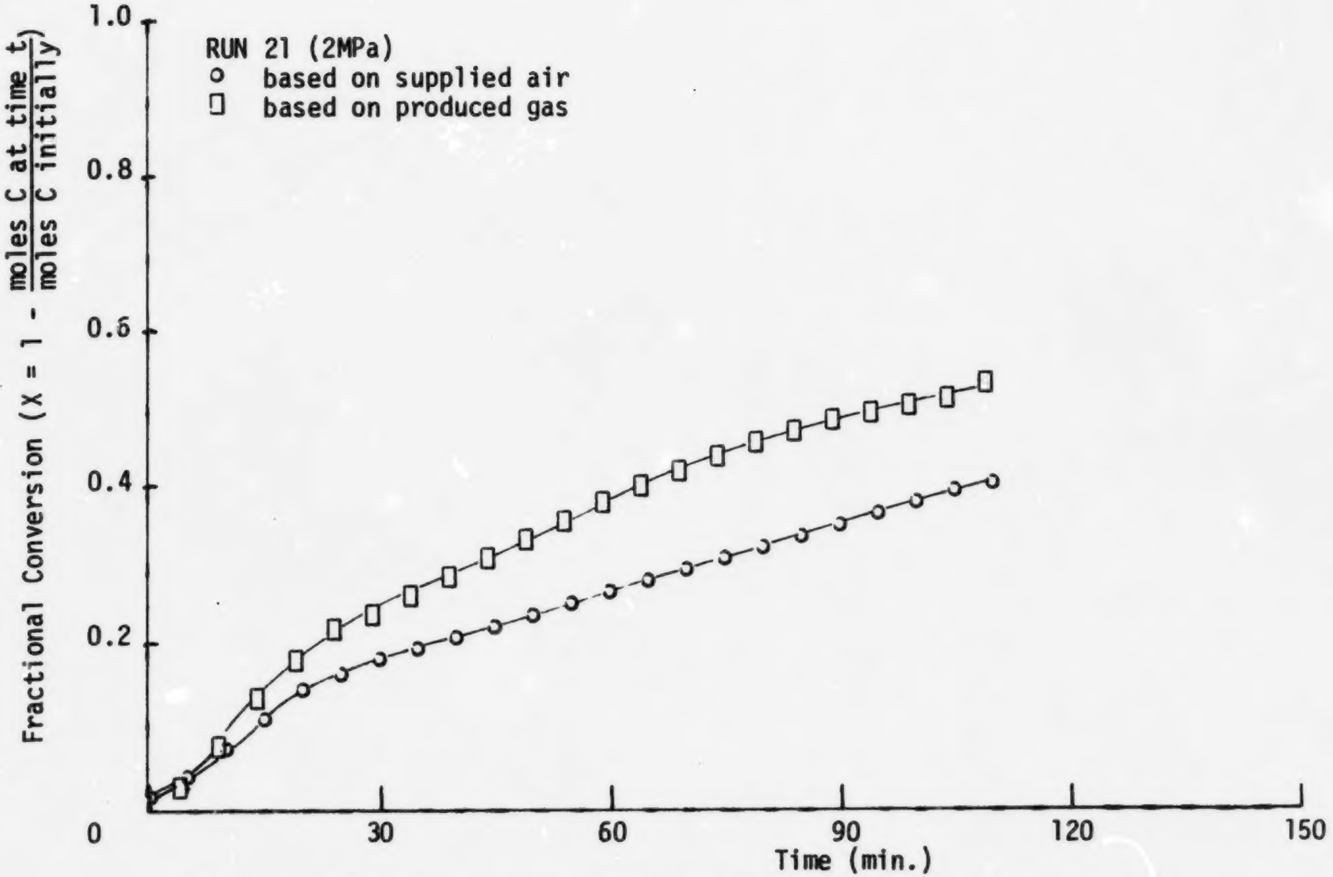

FIGURE 13. Fractional Conversion of Carbon as a Function of Time

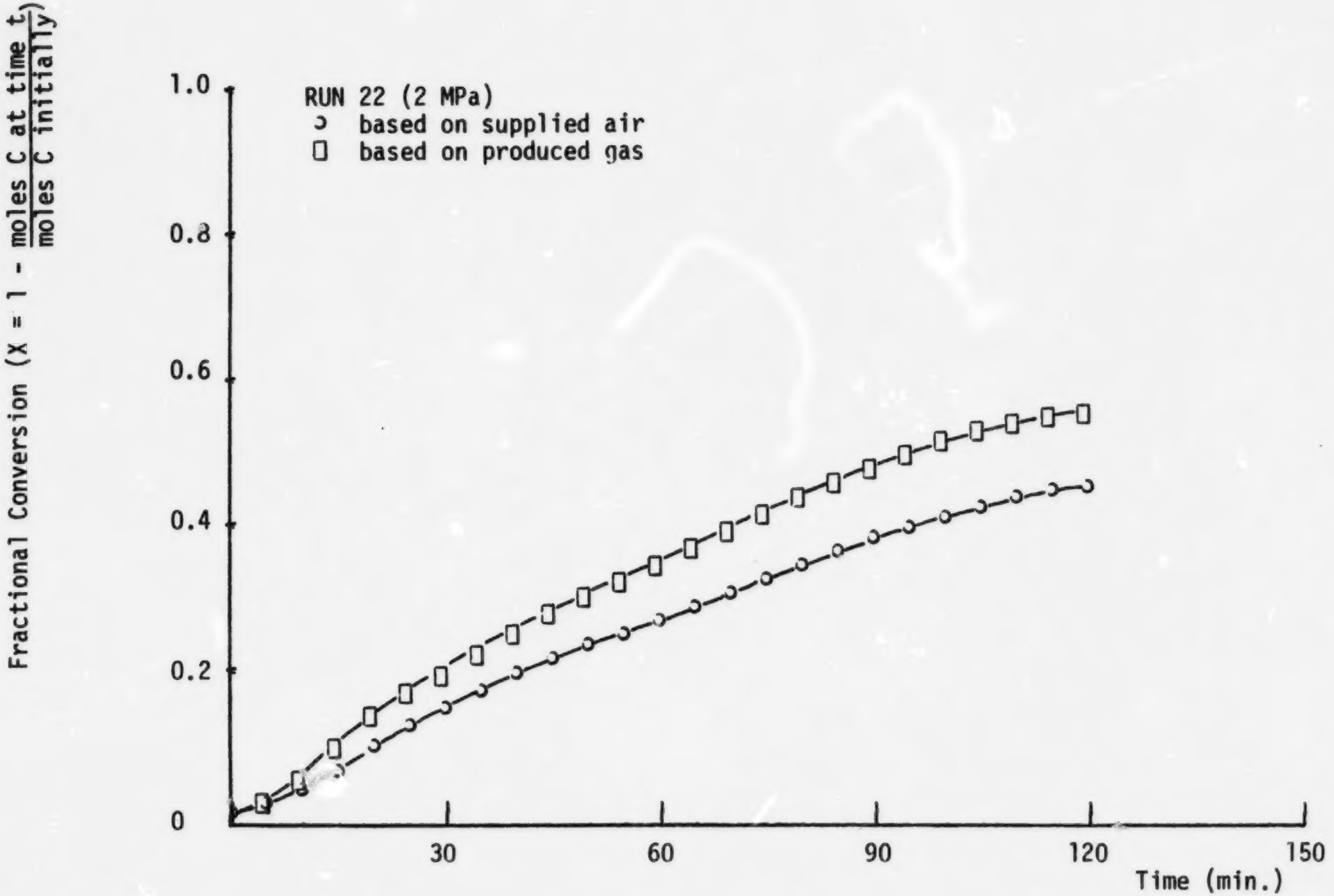

Figure 14. Fractional Conversion of Carbon as a Function of Time

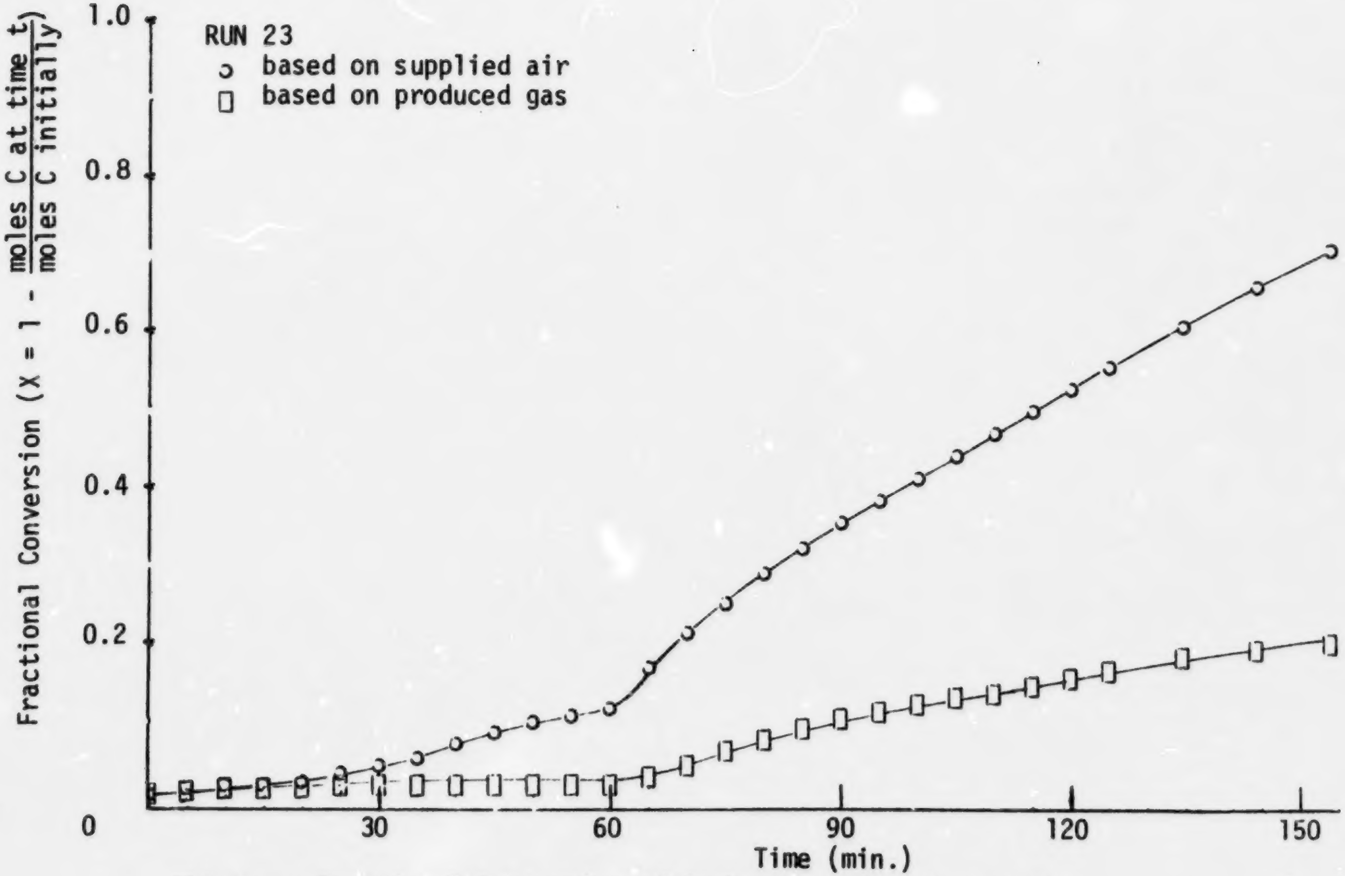

FIGURE 15. Fractional Conversion of Carbon as a Function of Time

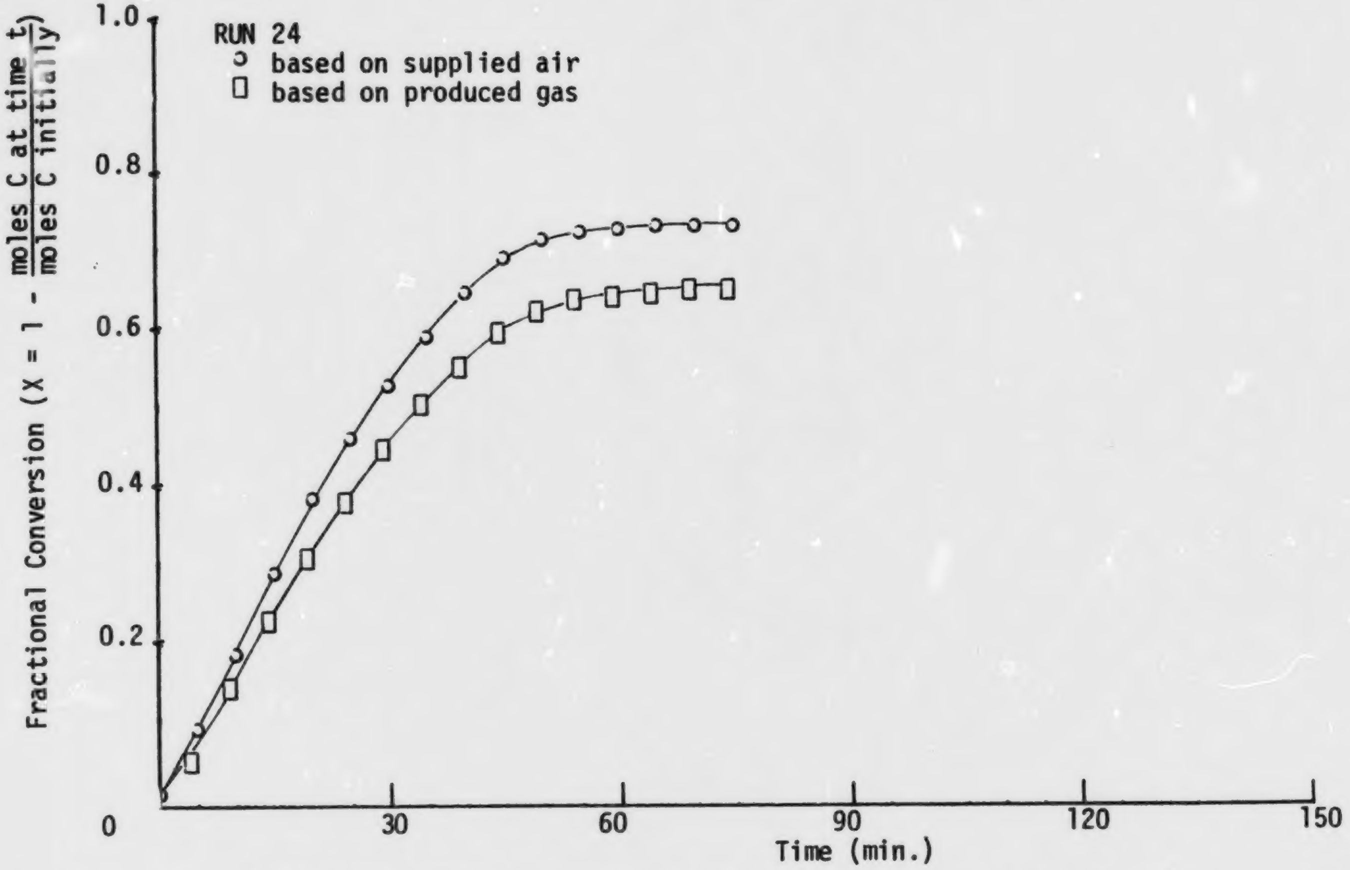

FIGURE 16. Fractional Conversion of Carbon as a Function of Time

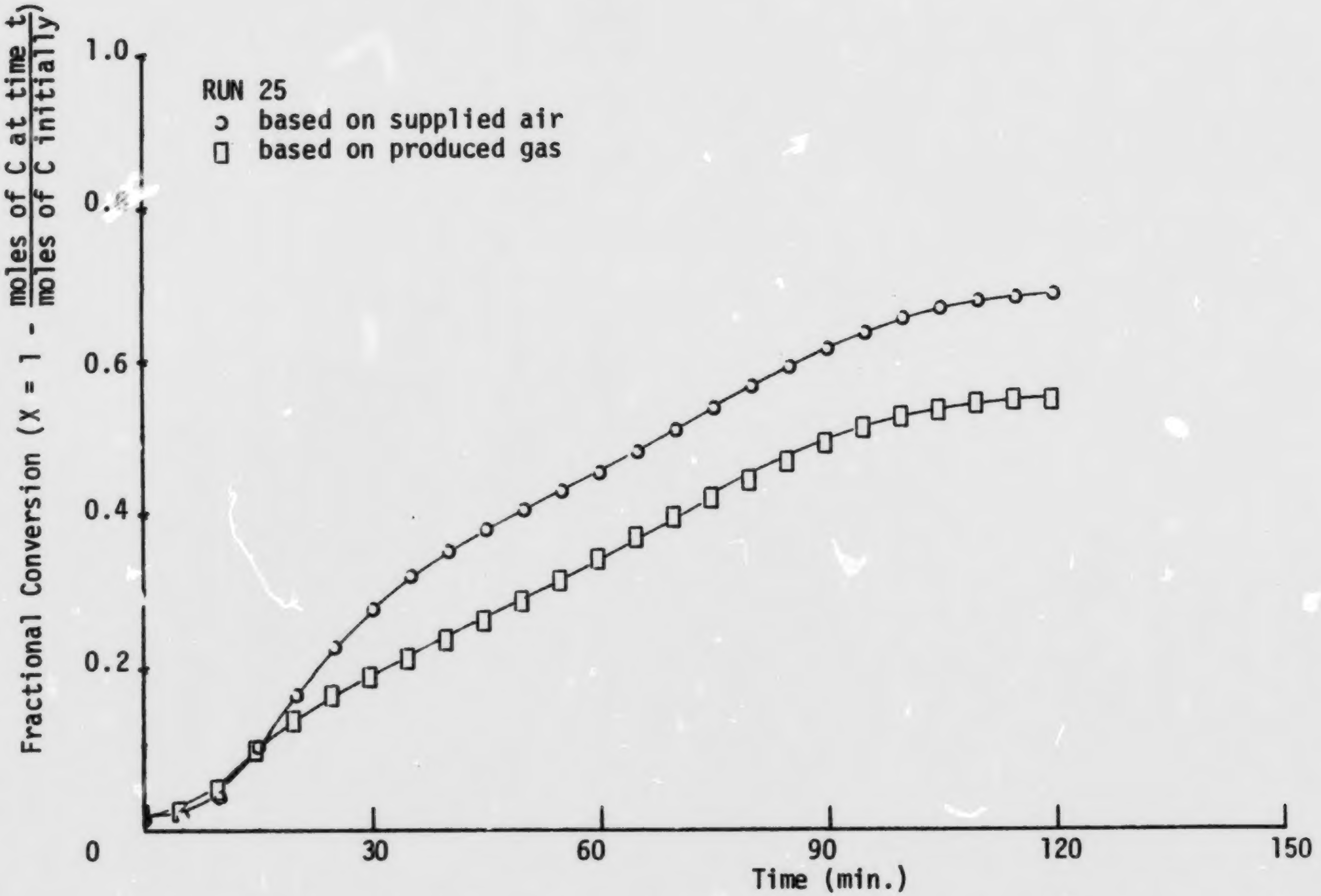

FIGURE 17. Fractional Conversion of Carbon as a Function of Time

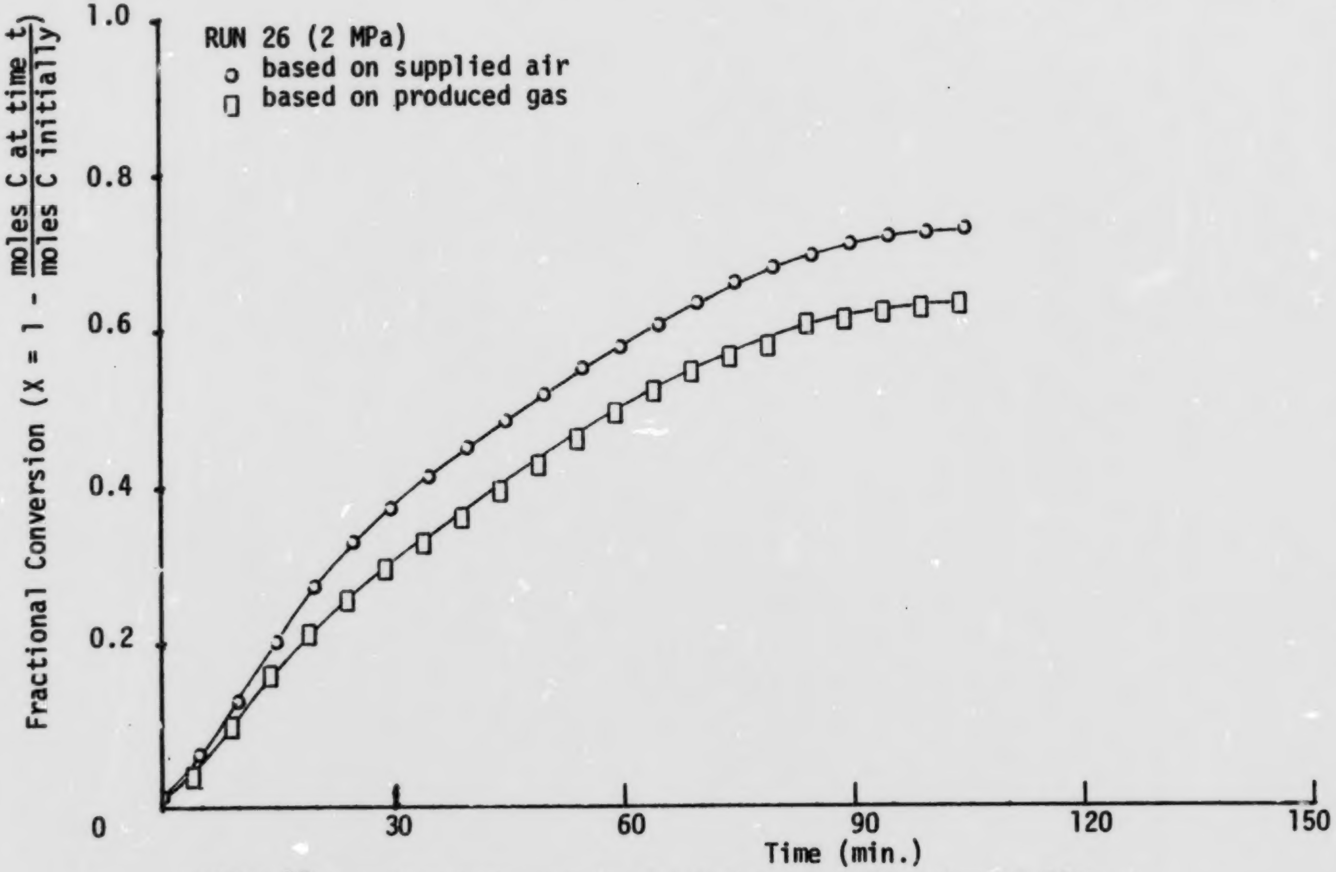

FIGURE 18 Fractional Conversion of Carbon as a Function of Time

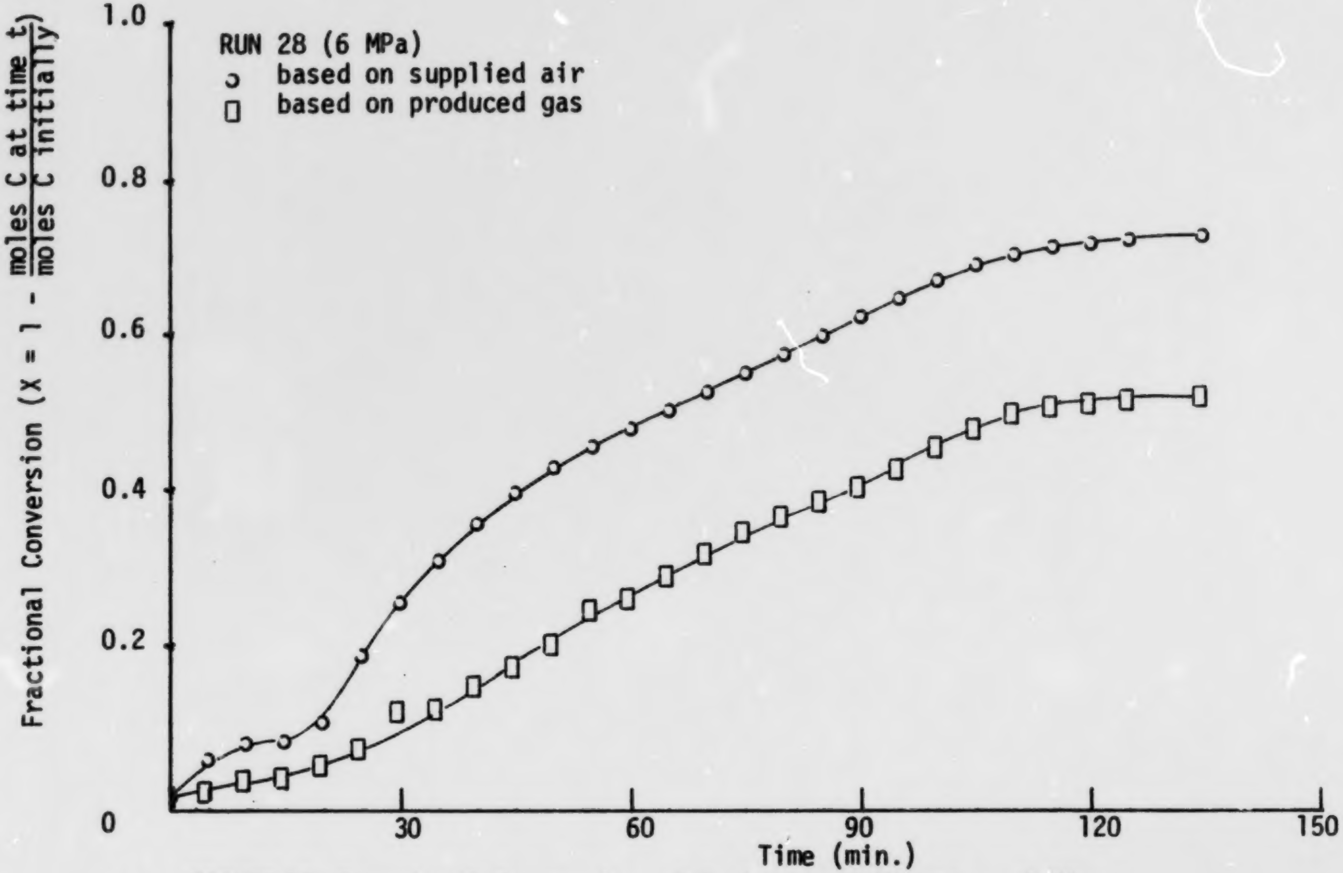

FIGURE 19. Fractional Conversion of Carbon as a Function of Time

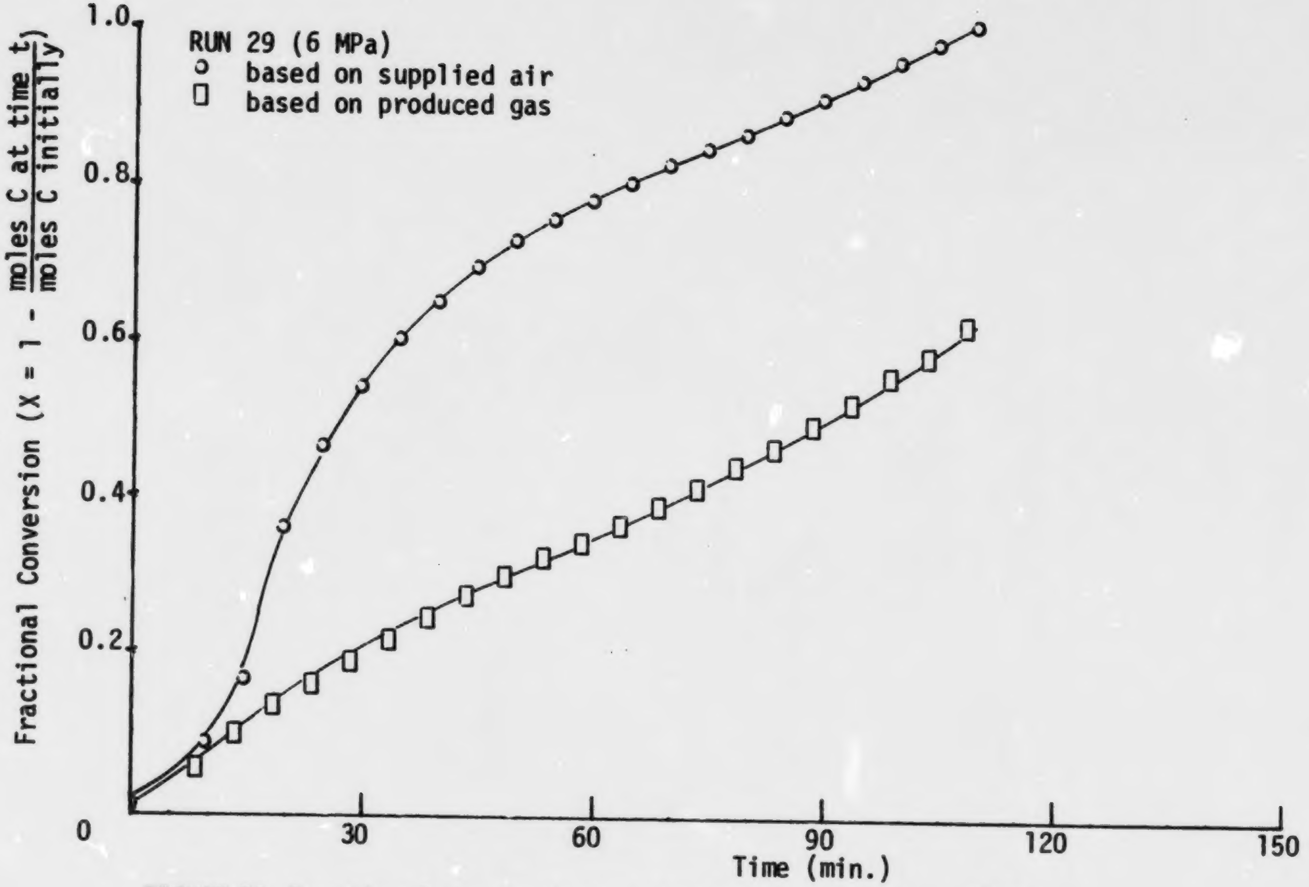

FIGURE 20. Fractional Conversion of Carbon as a Function of Time

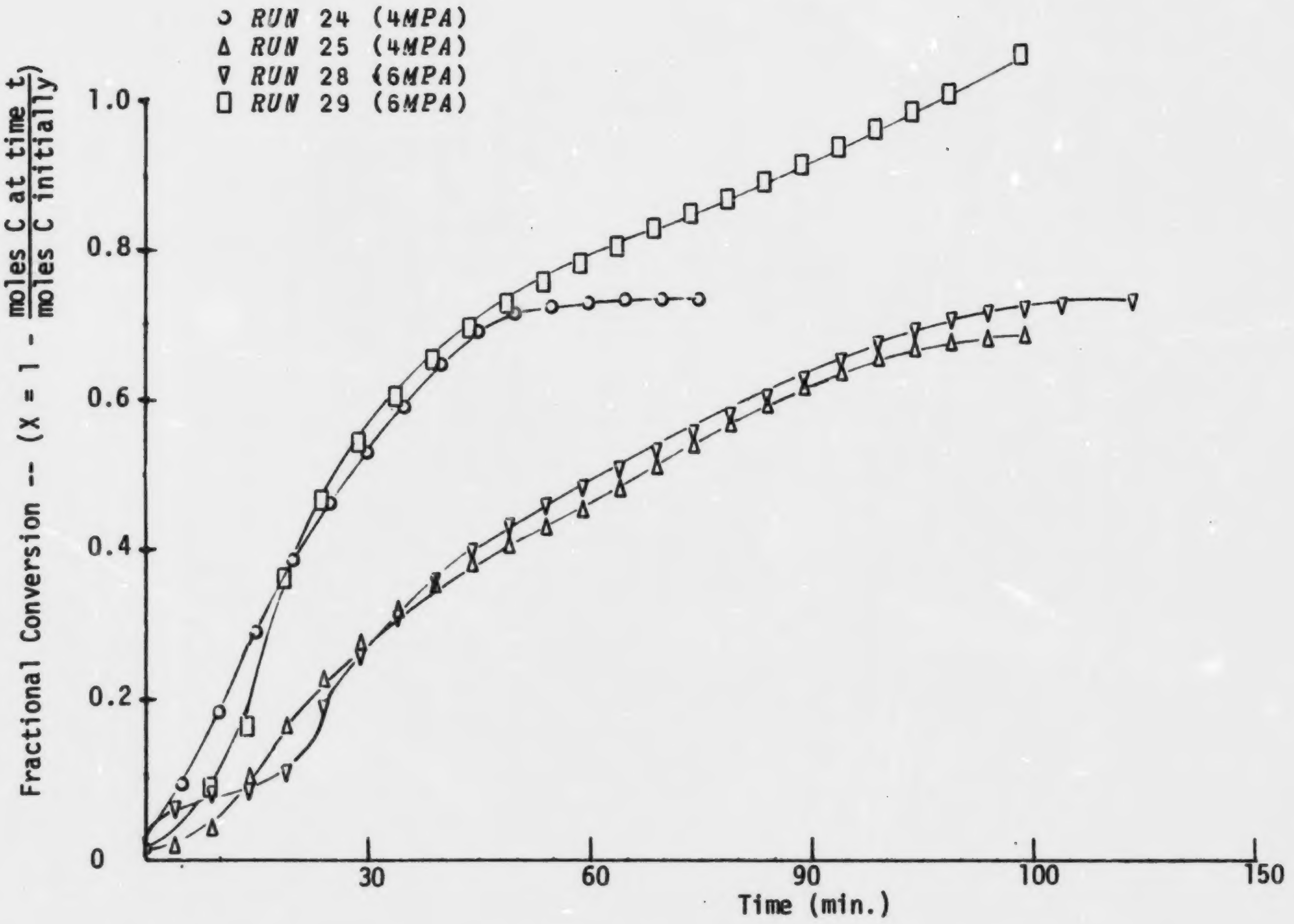

FIGURE 21. Fractional Conversion of Carbon as a Function of Time

Table 9. Total fractional carbon conversion

Calculated as $X = (1 - \frac{\text{total moles of C at end of reaction}}{\text{moles of C initially}})$

Run #	X_1*	X_2*	Run #	X_1	X_2
12	0.6	0.9	21	0.5	0.4
13	0.6	0.9	22	0.6	0.5
14	0.8	1.0	23	0.3	0.8
16	0.4	0.4	25	0.5	0.7
17	0.6	0.6	26	0.6	0.7
18	0.4	0.3	28	0.5	0.7
20	0.5	0.5	29	0.8	--

X_1 Total moles of carbon calculated based on produced gas volume.

X_2 Total moles of carbon calculated based on supplied air volume.

* Carbon dioxide calculated as $(0.2805 \times N_2) - (O_2 + 0.5 \times CO)$, the amount of CO_2 produced by devolatilization is therefore not included.

Table 10.

Residual Char/Ash After Gasification

Run #	Char/Ash g	Ash %	Calculated Ash g
12	62	74.6	46
13	73	64.6	47
14	47	79.8	38
15	37	93.9	35
16	110	42.9	47
17	58	25.4	15
18	49	91.4	45
19	41	95.7	39
20	66	72.6	48
21	38	95.8	36
22	45	97.4	44
23	45	97.0	44
24	52	99.3	52
25	52	98.7	51
26	50	98.4	49
27 *	11; 132	94.2; 30.9	51
28	38	96.7	37
29	57	97.2	55
30	196	26.2	51
31	17	92.4	16

* The ash sinter was physically removed from the char and both were analysed separately.

It is assumed that this loss results mainly from char/coal particles being carried from the reactor by the product gas stream. Evidence for this char "removal" was obtained from analyses of the remains of run 27. This high pressure run (6 MPa) had to be cancelled since a serious leak developed in the system, resulting in a large drop of the product gas flow rate.

After cool down a sintered ash "cake" of approximately 11 g, together with 132 g of char were removed from the reactor. The ash was located directly above the perforated disk, with the remaining char on top of the ash "cake". Determination of the ash content of both the ash "cake" and the char, by ashing at 950°C yielded a total of 51 g ash, or 81% of the amount expected. The ash content of the original lignite coal sample was 63 g as obtained from the proximate analysis. Part of the char is deposited on the walls of the tubing connecting the reactor with the knockout pot, as well as in the knockout pot itself. The remaining portion of this "char dust" is removed in the wash bottle.

The remains of run 27 also indicated that the combustion/gasification zone in the reactor remains approximately stationary and is situated directly above the perforated disk which serves as grate during the reaction. The thickness of a typical ash sinter after completion of a run is 4 - 5 cm for the high pressure reactor. The char moves slowly down during the course of the reaction.

The proximate analysis of the char/ash remains from the gasification runs are listed in table 4. Only those runs in which a steam/air mixture was used, (runs 18, 19, 21-27, 28 and 29) showed complete conversion.

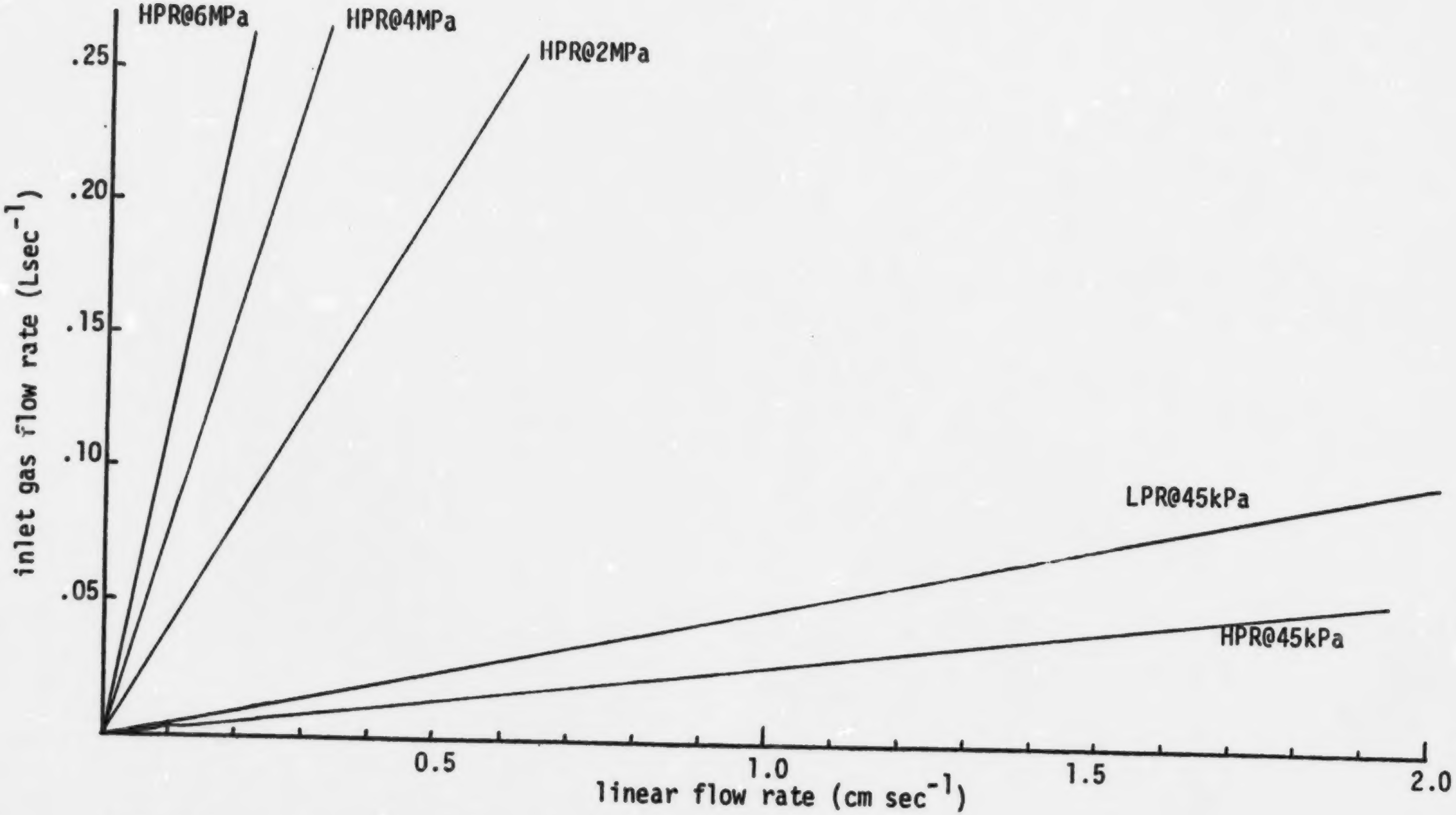

FIGURE 22. Pressure Dependence of Volume Flow Rate v.s. Linear Flow Rate

Analysis of the char/ash residues yielded 1 - 2% of carbon remains for reactions using steam/air mixtures. The carbon content for the remaining ash/char of reactions using air only varied from 16 - 53%. In all cases a rapid increase in oxygen content of the product gas together with a drop in reaction temperature signaled the end of the reactions.

6.3 Heating Value

The heating values obtained for the individual gas samples collected during each gasification run, together with the corresponding gas compositions are given in appendix 3. The values were calculated according to the methods outlined in the Gas Measurement Committee report No. 5, of the American Gas Association, Inc. The heating values and specific gravities for the pure components were taken from the above mentioned report. A series of programs to calculate the heating values is given in appendix 4.

During each of the gasification experiments the heating values of the samples peaked during the first part of the reaction as a result of rapid changes in the methane concentrations.

A measure of the total energy content of all the gas produced during a single experiment, was obtained by calculating the "average" gas composition. This "average" gas composition was calculated from the total number of moles accumulated for each gaseous component during a reaction. This "average" heating value was then multiplied by the total gas volume to yield the total energy content. It should be pointed out that when the total energy content is calculated by integrating the heating value time curve a slightly different value is obtained. The difference however is well within experimental error. This difference is due to the gas compressibility factor, which is a function of the gas composition. The method used here is equivalent to accumulating all gaseous components in a single reservoir, mix, and then determine the energy content, from the heating value for that mixture. The results are shown in table 11. The total energy content was not calculated for runs 12 - 20, since no accurate data for CO_2 was available for these runs. No definite trend was observed in either the average heating value or the total energy content.

6.4 Petrographic Studies

Petrographic studies on lignite coal samples were conducted at the University of Regina. Their findings are given in appendix 5.

Preliminary petrological studies were carried out on samples from the Estevan and Shaunavon areas. Petrological observations were conducted on three gasification ash/char samples. The samples investigated were the remains from preliminary test runs 9, 10 and 11. Unfortunately, no gas analysis data was available for these runs. Other commitments of the key personnel at the University of Regina and supplier problems and startup problems at our facilities made it impossible for both studies to be conducted in parallel. At a later date a subsidiary study was conducted on a char/ash sample produced in experiment 19. Analysis of both the coal sample before gasification, together with the rejected fines indicated that the discarded fines contained more silica but also some liptinite, a hydrogen rich, potential gas producing constituent. The ash/char was found to be comprised mostly of mineral matter and small percentages of coal of which 85 - 90% had reacted. Some sintered ash contained splinters of unreacted coal trapped in mineral matter.

Table 11. Total energy content of the gas produced during a run.

Run #	Average* Heating value MJ/m^3		Total gas volume m^3		Energy Content MJ	
	a	b	a	b	a	b
21	6.048	6.045	0.809	1.096	4.894	6.625
22	5.421	5.651	1.110	1.009	6.016	5.705
23	5.978	4.981	1.438	0.524	8.594	2.609
24	4.450	4.135	1.619	1.575	7.195	6.514
25	4.695	4.133	1.274	1.102	5.983	4.555
26	5.781	5.520	1.310	1.228	7.574	6.776
28	5.626	4.213	1.433	1.184	8.062	4.989
29	5.777	4.735	1.598	1.280	9.233	6.062

a based on supplied air volume

b based on produced gas volume

* Calculated from the total number of moles accumulated for each component.

The heat content of the coal sample used was:

Average heating value 16.713 MJ/kg

Energy content for 500 g of lignite coal sample 8.356 MJ

7. Conclusion and Recommendations

Reaction of Estevan lignite coal with steam/air mixtures resulted in complete gasification, yielding a residual ash containing 1 - 2% carbon. A carbon content of 16 - 53% was found in ash residues from reactions with air only.

The position of the reaction zone in the reactor zone remains steady and is located directly above the perforated disk, which supported the coal/char during gasification. The unreacted coal/char moved slowly down during the reactions, replacing the consumed coal. In the high pressure reactions the maximum concentration of methane measured in a product gas sample was 15%, this compared to a maximum of 8% measured during reactions at atmospheric pressure. The total yield of methane obtained from the gasification of 23.8 moles of carbon with air/steam at high pressure, varied from 1.0 to 2.6 moles. The yields of carbon dioxide and carbon monoxide varied from 3.4 - 9.3 moles and 5.2 - 6.3 moles respectively. The lowest concentration of nitrogen obtained in a product gas sample was 20%.

The high air flow rate can be held responsible for the loss of char/coal particles from the reactor, making it impossible to obtain a carbon balance. The use of nitrogen in air as a tracer gas gives good results for some reactions, but in some cases the discrepancies between calculated and measured product gas volumes are too large and indicate leaks in the experimental setup. Reduction in the gas flow rates would also allow for better temperature control, in addition to preventing particulate char/coal from leaving the reactor with the product gas steam. Slower flow rates would also allow smaller coal particles to be used, which according to petrological studies contain a high percentage of hydrogen rich liptinite, a potential gas producing constituent of the coal. As a further result of slower air flow rates it may also be possible to establish a steady state region of constant char gasification. This region would lie immediately after the devolatilization process. Comparison between the experimental parameters obtained for the run conducted at 4 MPa suggest the possibility of establishing such a region.

In order to reduce the time involved for the gas to reach the sample point after leaving the reactor, together with an attempt to reduce the large dilution effect for the gas samples taken during the early stages of the reaction, the following changes are suggested for the experimental setup:

a) the reduction of the interconnecting tubing between the boiler and the reactor.

b) the reduction of the distance between the reactor body and the coal hopper. This can be reduced by 30 cm, removing approximately 14 liters (at 6 MPa) dead volume.

c) the removal of the wash bottle and replacement of this with a series of stainless steel filters, attached directly to the knock out pot.

d) shortening of the connecting tubing between the boiler and the knock out pot. By turning the reactor 1/4 of a full turn, several leak prone connections could be eliminated.

e) the back pressure regulator could be connected directly to the filters near the knock out pot, reducing several feet of high pressure line. This also would increase the safety of the experimental setup since in that case no pressure lines other than those to the gauges would be outside the safety cubicle.

f) the sample line is to be connected directly to the reactor outlet, complete with its own filter and pressure reduction regulator.

g) an additional pressure transducer should be installed to be able to log the pressure drop over the metering orifice during the course of the experiment. This allows for more accurate flow calculations during the experiment.

h) the installation of a high pressure rotameter to provide direct flow readings.

i) the installation of a multipoint thermocouple in the reactor interior.

The present thermocouple wells used in the high pressure reactor penetrated 3 cm into the coal/char bed. The thermocouple well for the low pressure reactor penetrated 7.5 cm into the coal/char bed. The stable reaction temperature during the low pressure experiments may therefore have been the temperature of the coal/char rather than the reaction zone. A multi-point thermocouple would eliminate this problem.

8. Bibliography

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Appendix 1 - DETAILED EXPERIMENTAL CONDITIONS

Run 1 - 11

The first 11 experimental runs were conducted using the low pressure reactor. These runs were used to establish parameters such as heating rate of the reactor, maximum steam flow rate obtainable, and for calibration of rotameters and metering valve orifices. Steam flow rate tests showed that the boiler could not keep up with steam production at the maximum feed pump rate. Placing the boiler from a vertical position to a horizontal position solved this problem. These earlier tests also showed that the low pressure reactor could not be operated at a pressure of 27 kPa gauge as originally anticipated but that at least an inlet pressure of ~45 kPa gauge is required. Even at this pressure the pressure increase as a result from the initial devolatilization reactions is sometimes sufficient to reduce the feed gas rate, which in turn results in inaccuracies in measurement of the amount of air introduced into the reactor. The preliminary runs were also used to establish the coal particle size. Coal over 2.36 mm tends to "jam" in the hopper, and only tapping the hopper with an object may cause the coal to drop. This practice is unacceptable for high pressure operation since no personnel is allowed in the reactor enclosure once the reactor is pressurized. Coal particles maller than 1.0 mm tend to be carried from the reactor with the reaction gases. The optimum size proved to be 2.36 mm - 1.00 mm.

The parameters used for runs 12 through 31 are given below:

Run 12 (Air - Carbon)

Reactor: low pressure reactor at ~45 kPa (gauge)

Coal Sample: Estevan lignite 500 g

Moisture 10.7%, ash 16.5%, particle size 2.36 - 1.00 mm

Temperature:	Initial	Final	Average
Furnace (Central Zone)	833°C	817°C	842°C
Reactor interior	781°C	775°C	775°C

Air Flow Rate: 12.2 L/min

Duration of this run: 120 min

Total volume of gas produced: 1636 L

Total volume of steam condensed: ~100 mL

Total amount of ash/char remaining: 62 g

Gas Analysis: The product gas was analyzed for:

CH_4, CO, N_2, O_2 and H_2; CO_2 by difference

The gas compositions are given in Appendix 2.

Run 13 (Air - Carbon)

Reactor: low pressure reactor at ~45 kPa (gauge)

Coal Sample: Estevan lignite 500 g

Moisture 10.7%, ash 16.5%, particle size 2.36 - 1.00 mm

Temperature:	Initial	Final	Average
Furnace (Central Zone)	726°C	721°C	722°C
Reactor interior	615°C	685°C	712°C

Air flow rate: 12.2 L/min

Duration of this run: 165 min.

Total volume of gas produced: 2101 L

Total volume of steam condensed: ~75 mL

Total amount of ash/char remaining: 73 g

Gas Analysis: The product gas was analyzed for:

CH_4, CO, N_2, O_2, and H_2; CO_2 obtained by difference

The gas compositions are given in Appendix 2.

Run 14 (Air - Carbon)

Reactor: low pressure reactor at ~45 kPa (gauge)

Coal Sample: Estevan lignite 500 g

Moisture 10.7%, ash 16.5%, particle size 2.36 - 1.00 mm

Temperature:	Initial	Final	Average
Furnace (Central Zone)	924°C	966°C	951°C
Reactor interior	765°C	741°C	790°C

Air flow rate: 12.2 L/min

Duration of this run: 169 min

Total volume of gas produced: 2197 L

Total volume of steam condensed: ~75 mL

Total amount of ash/char remaining: 47 g

Gas Analysis: The product gas was analyzed for:

CH_4, CO, N_2, O_2 and H_2; CO_2 by difference

The gas compositions are given in Appendix 2.

Run 15 (Air - Carbon)

Reactor: low pressure reactor at ~450 kPa (gauge)

Coal Sample: Estevan lignite 500 g

Moisture 10.7%, ash 16.5%, particle size 2.36 - 1.00 mm

Temperature:	Initial	Final	Average
Furnace (Central Zone)	864°C	867°C	869°C
Reactor interior	700°C	675°C	726°C

Air flow rate: 12.2 L/min

Duration of this run: 115 min

Total volume of gas produced: 1512 L
Total volume of steam condensed: ~100 mL
Total amount of ash/char remaining: 37 g

Gas Analysis: The product gas was analyzed for:

CH_4, CO, N_2, O_2 and H_2: CO_2 by difference

The gas compositions are given in Appendix 2.

Run 16 (Air - Carbon)

Reactor: low pressure reactor at ∿45 kPa (gauge)

Coal Sample: Estevan lignite 500 g

Moisture 21.6%, ash 16.9%, particle size 2.36 - 1.00 mm

Temperature:	Initial	Final	Average
Furnace (Central Zone)	$669^{\circ}C$	$670^{\circ}C$	$670^{\circ}C$
Reactor interior	$650^{\circ}C$	$651^{\circ}C$	$663^{\circ}C$

Air flow rate: 9.7 L/min

Duration of this run: 109 min

Total volume of gas produced: 1246 L

Total volume of steam condensed: 76 mL

Total amount of ash/char remaining: 110 g

Gas Analysis: The product gas was analyzed for:

CH_4, CO, N_2, O_2 and H_2; CO_2 obtained by difference

The gas compositions are given in Appendix 2.

Run 17 (Air - Carbon)

Reactor: low pressure reactor at ∿45 kPa (gauge)

Coal Sample: Estevan lignite 500 g

Moisture 21.6%, ash 16.9%, particle size 2.36 - 1.00 mm

Temperature:	Initial	Final	Average
Furnace (Central Zone)	$670^{\circ}C$	$672^{\circ}C$	$670^{\circ}C$
Reactor interior	$647^{\circ}C$	$687^{\circ}C$	$685^{\circ}C$

Air flow rate: 9.7 L/min

Duration of this run: 112 min

Total volume of gas produced: 1400 L

Total volume of steam condensed: 78 mL

Total amount of ash/char remaining: 58 g

Gas Analysis: The product gas was analyzed for:

CH_4, CO, N_2, O_2 and H_2; CO_2 by difference

The gas compositions are given in Appendix 2.

Run 18 (Air - Steam - Carbon)

Reactor: low pressure reactor at ∿45 kPa (gauge)

Coal Sample: Estevan lignite 500 g

Moisture 27.8%, ash 13.9%, particle size 2.36 - 1.00 mm

Temperature:	Initial	Final	Average
Furnace (Central Zone)	649°C	627°C	621°C
Reactor interior	669°C	674°C	671°C

Air flow rate: 7.7 L/min during first 50 min
9.7 L/min during remainder of reaction

Steam Flow Rate: 7.4 g/min for 85 min

Total amount of steam supplied: 629 g

Duration of this run: 105 min

Total volume of gas produced: 1512 L

Total volume of steam condensed: 308 mL

Total amount of ash/char remaining: 49 g

Gas Analysis: The product gas was analyzed for:
CH_4, CO, N_2, O_2 and H_2; CO_2 by difference

The gas compositions are given in Appendix 2.

Run 19 (Air - Steam - Carbon)

Reactor: low pressure reactor at ∿45 kPa (gauge)

Coal Sample: Estevan lignite 500 g

Moisture 27.7%, ash 13.9%, particle size 2.36 - 1.00 mm

Temperature:	Initial	Final	Average
Furnace (Central Zone)	983°C	972°C	974°C
Reactor interior	941°C	915°C	912°C

Air flow rate: 7.2 L/min

Steam flow rate: 6.4 g/min for 55 min

Total amount of steam supplied: 408 g

Duration of this run: 65 min

Total volume of gas produced: 1130 L

Total volume of steam condensed: 175 mL

Total amount of ash/char remaining: 47 g

Gas Analysis: The product gas was analyzed for:
CH_4, CO, N_2, O_2 and H_2; CO_2 by difference

The gas compositions are given in Appendix 2.

Run 20 (Air - Carbon)

Reactor: low pressure reactor at ~45 kPa (gauge)

Coal Sample: Estevan lignite 500 g

Moisture 21.6%, ash 13.9%, particle size 2.36 - 1.00 mm

Temperature:	Initial	Final	Average
Furnace (Central Zone)	981°C	978°C	982°C
Reactor interior	912°C	912°C	926°C

Air flow rate: 7.7 L/min

Duration of this run: 120 min

Total volume of gas produced: 1248 L

Total volume of steam condensed: 129 mL

Total amount of ash/char remaining: 66 g

Gas Analysis: The product gas was analyzed for:

CH_4, CO, N_2, O_2 and H_2; CO_2 by difference

The gas compositions are given in Appendix 2.

Run 21 (Air - Steam - Carbon)

Reactor: High pressure reactor at 2 MPa (gauge)

Coal Sample: Estevan lignite 500 g

Moisture 26.9%, ash 12.6%, particle size 2.36 - 1.00 mm

Temperature:	Initial	Final	Average
Furnace (Central Zone)	684°C	688°C	685°C
Reactor interior	671°C	316°C	866°C

Air flow rate: 7 L/min for first 20 min, then changed to 3.6 L/min for the remainder of the run

Steam flow rate: 5.1 g/min

Total amount of steam supplied: 550 g

Duration of this run: 110 min

Total volume of gas produced: 1096 L

Total volume of steam condensed: 29 mL

Total amount of ash/char remaining: 38.1 g

Gas Analysis: The product gas was analyzed for:

CH_4, CO_2, CO, C_2H_6, N_2, O_2 and H_2

The gas compositions are given in Appendix 2.

The air flow rate was cut back after the internal reactor temperature reached 1020°C.

Run 22 (Air - Steam - Carbon)

Reactor: high pressure reactor at 2 MPa (gauge)

Coal Sample: Estevan lignite 500 g
Moisture 26.9%, ash 12.6%, particle size 2.36 - 1.00 mm

Temperature:	Initial	Final	Average
Furnace (Central Zone)	686°C	692°C	690°C
Reactor interior	660°C	652°C	893°C

Air flow rate: 4.1 L/min

Steam flow rate: 5.6 g/min

Total amount of steam supplied: 674 g

Duration of this run: 120 min

Total volume of gas produced: 1009 L

Total volume of steam condensed: ∿40 mL

Total amount of ash/char remaining: 45 g

Gas Analysis: The product gas was analyzed for:
CH_4, CO_2, CO, C_2H_6, N_2, O_2 and H_2

The gas compositions are given in Appendix 2.

The air flow rate slowly decreased after ∿90 min, due to premature exhaustion of compressed air, as a result of a leak in the supply line.

Run 23 (Air - Steam - Carbon)

Reactor: high pressure reactor at 2 MPa (gauge)

Coal Sample: Estevan lignite 500 g
Moisture 26.9%, ash 12.6%, particle size 2.36 - 1.00 mm

Temperature:	Initial	Final	Average
Furnace (Central Zone)	689°C	689°C	696°C
Reactor interior	662°C	657°C	741°C

Air flow rate: 1.4 L/min for the first 65 min, the flow rate was then increased to 4.9 L/min for the remainder of the run

Steam flow rate: 5.7 g/min

Total amount of steam supplied: 1148 g

Duration of this run: 200 min

Total volume of gas produced: 524 L

Total volume of steam condensed: 338 mL

Total amount of ash/char remaining: 45 g

Gas Analysis: The product gas was analyzed for:
CH_4, CO_2, CO, C_2H_6, N_2, O_2 and H_2

The gas compositions are given in Appendix 2.

The pressure drop over the metering orifice proved too small, introducing a large error in the flow rate.

Run 24 (Air - Steam - Carbon)

Reactor: high pressure reactor at 4 MPa (gauge)

Coal Sample: Estevan lignite 500 g

Moisture 26.9%, ash 12.6%, particle size 2.36 - 1.00 mm

Temperature:	Initial	Final	Average
Furnace (Central Zone)	680°C	695°C	694°C
Reactor Interior	656°C	671°C	857°C

Air flow rate: 15.4 L/min

Steam flow rate: 12.6 g/min

Total amount of steam supplied: 944 g

Duration of this run: 75 min

Total volume of gas produced: 1575 L

Total volume of steam condensed: 705 mL

Total amount of ash/char remaining: 51.9 g

Gas Analysis: The product gas was analyzed for:

CH_4, CO_2, CO, C_2H_6, N_2, O_2 and H_2

The gas compositions are given in Appendix 2.

Run 25 (Air - Steam - Carbon)

Reactor: high pressure reactor at 4 MPa (gauge)

Coal Sample: Estevan lignite 500 g

Moisture 26.9%, ash 12.6%, particle size 2.36 - 1.00 mm

Temperature:	Initial	Final	Average
Furnace (Central Zone)	684°C	703°C	693°C
Reactor interior	656°C	643°C	844°C

Air flow rate: 7.5 L/min

Steam flow rate: 13.8 g/min

Total amount of steam supplied: 1449 g

Duration of this run: 115 min

Total volume of gas produced: 1102 L

Total volume of steam condensed: 725 mL

Total amount of ash/char remaining: 52 g

Gas Analysis: The product gas was analyzed for:

CH_4, CO_2, CO, C_2H_6, N_2, O_2 and H_2

The gas compositions are given in Appendix 2.

Run 26 (Air - Steam - Carbon)

Reactor: high pressure reactor at 2 MPa (gauge)

Coal Sample: Estevan lignite 500 g
Moisture 26.0%, ash 12.7%, particle size 2.36 - 1.00 mm

Temperature:	Initial	Final	Average
Furnace (Central Zone)	687°C	697°C	692°C
Reactor interior	655°C	654°C	775°C

Air flow rate: 7 L/min

Steam flow rate: 13.6 g/min

Total amount of steam supplied: 1412 g

Duration of this run: 100 min

Total volume of gas produced: 1228 L

Total volume of steam condensed: 740 mL

Total amount of ash/char remaining: 50 g

Gas Analysis: The product gas was analyzed for:
CH_4, CO_2, CO, C_2H_6, N_2, O_2 and H_2

The gas compositions are given in Appendix 2.

Run 27 (Air - Steam - Carbon)

Reactor: high pressure reactor at 6 MPa (gauge)

Coal Sample: Estevan lignite 500 g
Moisture 26.0%, ash 12.7%, particle size 2.36 - 1.00 mm

Temperature:	Initial	Final	Average
Furnace (Central Zone)	689°C	664°C	682°C
Reactor interior	653°C	784°C	801°C

Air flow rate: 6.9 L/min

Steam flow rate: 12.0 g/min

Total amount of steam supplied: 340 g

Duration of this run: 30 min

Total volume of gas produced: 140 L

Total volume of steam condensed: not determined

Total amount of ash/char remaining: 11 g ash, 132 g char

Gas Analysis: The product gas was analyzed for:
CH_4, CO_2, CO, C_2H_6, N_2, O_2 and H_2

The gas compositions are given in Appendix 2.

After 25 min the reaction had to be aborted due to a serious leak in the reactor to knock out pot interconnecting tubing.

Run 28 (Air - Steam - Carbon)

Reactor: high pressure reactor at 6 MPa (gauge)

Coal Sample: Estevan lignite 500 g

Moisture 26.0%, ash 12.7%, particle size 2.36 - 1.00 mm

Temperature:	Initial	Final	Average
Furnace (Central Zone)	688°C	702°C	695°C
Reactor interior	657°C	633°C	804°C

Air flow rate: 6.9 L/min

Steam flow rate: 12.2 g/min

Total amount of steam supplied: 1581 g

Duration of this run: 135 min

Total volume of gas produced: 1184 L

Total volume of steam condensed: 1360 mL

Total amount of ash/char remaining: 38 g

Gas Analysis: The product gas was analyzed for:

CH_4, CO_2, CO, C_2H_6, N_2, O_2 and H_2

The gas compositions are given in Appendix 2.

Relatively fast depressurization of the reactor at the end of the run may have carried over to the knock out pot.

Run 29 (Air - Steam - Carbon)

Reactor: high pressure reactor 6 MPa (gauge)

Coal Sample: Estevan lignite 500 g

Moisture 26.0%, ash 12.7%, particle size 2.36 - 1.00 mm

Temperature:	Initial	Final	Average
Furnace (Central Zone)	687°C	703°C	695°C
Reactor interior	656°C	635°C	844°C

Air flow rate: 6.9 L/min

Steam flow rate: 11.3 g/min

Total amount of steam supplied: 1591 L

Duration of this run: 135 min

Total volume of gas produced: 1280 L

Total volume of steam condensed: 1340 g

Total amount of ash/char remaining: 57 g

Gas Analysis: The product gas was analyzed for:

CH_4, CO_2, CO, C_2H_6, N_2, O_2 and H_2

The gas compositions are given in Appendix 2.

Run 30 (pyrolysis)

Reactor: high pressure reactor at 2 MPa (gauge)

Coal Sample: Estevan lignite

Moisture 26.2%, ash 12.0%, particle size 2.36 - 1.00 mm

Temperature:	Initial	Final	Average
Furnace (Central Zone)	830°C	836°C	831°C
Reactor interior	817°C	811°C	796°C

Nitrogen flow rate: 7.0 L/min

Duration of this run: 70 min

Total volume of gas produced: 663 L

Total volume of steam condensed: 190 mL

Total amount of ash/char remaining: 196 g char

Gas Analysis: The product gas was analyzed for:

CH_4, CO_2, CO, C_2H_6, N_2, O_2 and H_2

The gas compositions are given in Appendix 2.

The reactor was continously flowed with nitrogen during this run.

Run 31 (Air - Steam - Carbon)

Reactor: high pressure reactor ∼ 45 kPa (gauge)

Coal Sample: Estevan lignite 500 g

Moisture 26.2%, ash 12.0%, particle size 2.36 - 1.00 mm

Temperature:	Initial	Final	Average
Furnace (Central Zone)	692°C	696°C	695°C
Reactor interior	678°C	621°C	665°C

Air flow rate: 5.0 L/min for first 45 min, then changed to 7.3 L/min for the next 20 min, then changed to 7.6 L/min for remainder of the run

Steam flow rate: 14.7 g/min

Total amount of steam supplied: 1115 g

Duration of this run: 85 min

Total volume of gas produced: 791 L

Total volume of steam condensed: 980 g

Total amount of ash/char remaining: 17 g

Gas Analysis: The product gas was analyzed for:

CH_4, CO_2, CO, C_2H_6, N_2, O_2 and H_2

The gas compositions are given in Appendix 2.

The pressure slowly increased to 200 kPa/g over the duration of the reaction. The flow rate was increased to offset this rise in pressure, worsening the situation. The steam flow was interrupted after 45 minutes for a 20 min. time period in an attempt to increase the temperature.

Appendix 2 PRODUCT GAS COMPOSITIONS

The product gas compositions as a function of time are given for all samples collected during runs 12 through 31. The heating value for each sample was calculated on a dry gas basis at 15^{o}C and 101.325 kPa. The heating values were calculated using the programs listed in appendix 4, and are based on the methods outlined in the Gas Measurement Committee report No. 5, of the American Gas Association,Inc.

The amount of CO_2 in samples 12 through 21 A was calculated as $(0.2805 \times N_2) - (O_2 + 0.5 \times CO)$, before renormalization to 100%, total composition.

RUN 12 ESTEVAN LIGNITE (AIR CARBON) ~45KPA

SAMPLE NO.	TIME MIN.	TEMP. °C	COMPOSITION IN VOLUME PERCENT CO2	H2	C2	O2	N2	CH4	CO	SPECIFIC HEAT MJ/M3 *
	0	718								
1	5	670		89.6		0.8	6.0	0.8	2.8	11.478
2	10	742	0.3	22.6		0.8	46.9	5.3	24.1	7.663
3	15	771		77.3		1.4	13.0	2.1	6.1	10.897
4	20	780		77.1		1.2	15.1	0.2	6.5	10.170
5	25	784	3.1	5.5		1.0	63.2		27.3	3.972
6	30	786	3.4	3.7		1.0	64.5		27.4	3.761
7	35	788	< 0.1	86.0		0.8	9.5		3.7	10.847
8	40	788	3.9			1.2	67.4		27.5	3.327
9	45	789	1.6	61.3		0.4	26.1		10.7	9.720
10	50	783	3.4	15.5		0.9	56.9		23.3	4.706
11	55	788	0.1	76.6		1.3	15.9		6.0	9.991
12	60	788	4.7			1.0	67.7		26.5	3.213
13	65	788	5.2			1.1	68.1		25.6	3.093
14	70	788	5.2	3.8		1.1	65.6		24.3	3.409
15	75	788	0.6	75.1		1.4	17.2		5.7	9.775
16	80	737	9.8			1.1	71.0		18.1	2.193
17	35	785	8.2			1.1	70.0		20.7	2.505
13	30	785	9.8			1.1	71.0		13.1	2.133
19	95	783	10.0			2.8	72.3		14.9	1.807
20	100	783	13.3			1.1	73.3		12.2	1.479
21	105	782	12.7			1.2	73.0		13.2	1.597
22	110	780	15.4			1.1	74.7		8.8	1.063
23	115	777	16.9			1.2	75.6		6.3	0.763
24	120	775	20.3			1.3	77.9		0.5	0.064

* AT 15°C AND 101.325 KPA

CO_2 calculated as $(0.2805 \times N_2)-(O_2+0.5 \times CO)$

RUN 13   ESTEVAN LIGNITE   (AIR CARBON)   ~45KPA

SAMPLE NO.	TIME MIN.	TEMP. •C	COMPOSITION IN VOLUME PERCENT CO2	H2	C2	O2	N2	CH4	CO	SPECIFIC HEAT MJ/M3 *
	0	615								
1	5	627	3.2	18.2		1.6	52.5	4.6	19.9	6.370
2	10	687		64.6		2.4	22.2	1.8	9.1	9.593
3	15	712	0.3	62.5		1.5	24.2	1.6	10.0	9.384
4	20	719	3.0	15.6		0.8	54.9	2.4	23.3	5.646
5	25	721	< 0.1	72.1		1.7	18.8	0.2	7.2	9.668
6	30	723	1.1	69.9		1.0	20.6		7.4	9.364
7	35	725	2.8	48.3		0.5	35.2		13.2	7.461
8	40	728	2.3	52.4		0.8	32.5	< 0.1	11.9	7.813
9	45	729	0.4	60.4		2.5	27.3		9.4	8.457
10	50	730				8.5	68.7		22.7	2.750
11	55	730	3.6	49.6		0.5	34.9		11.4	7.405
12	60	730	3.6	46.8		0.5	36.3		12.2	7.156
13	65	730	8.3			1.0	70.0		20.6	2.500
14	70	730	5.4	36.8		1.0	44.6		12.2	5.957
15	75	729	2.8			8.8	71.5		16.9	2.046
16	80	729	12.5			0.9	72.6		14.0	1.692
17	85	728	13.1			1.7	73.5		11.7	1.420
18	90	728	14.1			1.8	74.3		9.7	1.181
19	95	726	15.5			2.2	75.5		6.7	0.818
20	100	725	16.9			1.7	76.0		5.5	0.665
21	105	723	18.9			1.1	76.9		3.1	0.376
22	110	721	17.3			4.5	78.1		< 0.1	0.011
23	115	720	19.0			2.9	78.1			
24	120	718	17.0			4.9	78.1			
25	125	715	14.5			7.4	78.1			
26	130	712	12.5			9.4	78.1			
27	135	708	12.2			9.7	78.1			
28	140	705	9.7			12.2	78.1			
29	145	699	8.9			13.0	78.1			
30	150	695	7.5			14.4	78.1			
31	155	691	7.3			14.6	78.1			
32	160	688	5.6			16.4	78.1			
33	165	685	5.8			16.1	78.1			

* AT 15•C AND 101.325 KPA

CO_2 calculated as $(0.2805 x N_2) - (O_2 + 0.5 x CO)$

RUN 14 ESTEVAN LIGNITE (AIR CARBON) ~45KPA

SAMPLE NO.	TIME MIN.	TEMP. °C	COMPOSITION IN VOLUME PERCENT CO2	H2	C2	O2	N2	CH4	CO	SPECIFIC HEAT MJ/M3 *
	0	765								
1	5	726		25.2		1.7	41.8	8.0	23.3	8.921
2	10	766		27.4		3.5	42.1	4.9	22.0	7.854
3	15	787		18.5		2.0	51.5	2.4	25.6	6.255
4	20	793	0.6	48.2		0.7	34.0		16.5	7.843
5	25	795	1.2	46.6		1.8	36.1		14.4	7.396
6	30	797	1.3	2.5		2.9	65.2		28.1	3.707
7	35	800	2.4	2.3		2.0	65.4		27.9	3.667
8	40	801	2.5	1.6		2.9	66.5		26.5	3.401
9	45	803	1.7	1.7		2.9	65.9		27.8	3.576
10	50	805	1.5	2.2		3.2	65.7		27.4	3.582
11	55	806				5.8	67.3		26.8	3.248
12	60	808	0.7			4.7	67.5		27.1	3.277
13	65	810	2.6			2.6	67.4		27.4	3.311
14	70	810	3.3			2.9	68.0		25.8	3.125
15	75	812	3.8			2.2	67.9		26.0	3.149
16	80	812	3.5			2.7	68.0		25.7	3.114
17	84	812	1.5			5.9	68.8		23.8	2.879
18	89	813	5.8			2.1	69.1		23.0	2.781
19	94	814	5.4			3.3	69.7		21.6	2.616
20	99	814	7.9			2.7	70.9		18.5	2.245
21	104	813	10.8			3.4	73.2		12.6	1.532
22	109	809	14.5			3.8	75.8		6.0	0.726
23	114	805	15.5			5.0	77.2		2.3	0.279
24	119	805	15.2			6.7	78.1			
25	124	802	15.9			6.1	78.1			
26	129	800	16.7			5.2	78.1			
27	134	795	11.7			10.2	78.1			
28	139	784	8.5			13.4	78.1			
29	144	774	6.9			15.0	78.1			
30	149	767	5.4			16.6	78.1			
31	154	761	5.6			16.3	78.1			
32	159	755	4.1			17.8	78.1			
33	164	749	4.6			17.3	78.1			
34	169	745	1.2			20.7	78.1			

* AT 15°C AND 101.325 KPA

CO_2 calculated as $(0.2805 \times N_2) - (O_2 + 0.5 \times CO)$

RUN 15 ESTEVAN LIGNITE (AIR CARBON) ~45KPA

SAMPLE NO.	TIME MIN.	TEMP. °C	COMPOSITION IN VOLUME PERCENT CO2	H2	C2	O2	N2	CH4	CO	SPECIFIC HEAT MJ/M3 *
	0	700								
1	5	679	1.5	65.0		0.4	22.5	1.7	9.0	9.604
2	15	712	0.3	88.7		0.3	7.5	0.3	2.9	11.171
3	20	728	1.0	56.7		1.0	28.5	0.8	11.9	8.618
4	25	733	1.1			3.1	66.4	0.5	28.3	3.692
5	30	738	2.8			1.6	66.9		28.7	3.468
6	35	740	0.4	50.7		2.2	33.2		13.5	7.791
7	40	743	1.8	41.6		1.1	39.3		16.2	7.012
8	50	747	2.9			1.7	67.1		28.3	3.422
9	55	750	4.3			3.2	68.8		23.7	2.874
10	60	751	6.7			1.7	69.4		22.3	2.695
11	65	754	9.1			2.4	71.4		17.2	2.086
12	70	753	17.2			1.9	76.3		4.6	0.560
13	80	751	16.9			4.3	78.0		0.2	0.027
14	85	750	13.8			8.1	78.1			
15	90	746	12.0			9.9	78.1			
16	95	735	9.9			12.0	78.1			
17	100	717	3.7			18.2	78.1			
18	105	692	2.9			19.0	78.1			
19	110	682	2.7			19.2	78.1			
20	115	675	2.6			19.3	78.1			

* AT 15°C AND 101.325 KPA

CO_2 calculated as $(0.2805 \times N_2) - (O_2 + 0.5 \times CO)$

RUN 16 ESTEVAN LIGNITE (AIR CARBON) ~45KPA

SAMPLE NO.	TIME MIN.	TEMP. °C	COMPOSITION IN VOLUME PERCENT CO2	H2	C2	O2	N2	CH4	CO	SPECIFIC HEAT MJ/M3 *
	0	650								
1	4	602	2.4	72.5		1.8	19.9	0.7	2.7	9.374
2	6	619	11.1	9.9		1.4	63.8	3.0	10.8	3.660
3	8	628	8.3	8.4		4.4	64.0	4.4	10.4	3.962
4	10	628	7.0	21.1		1.9	53.0	5.0	12.0	5.932
5	12	638	6.7	19.0		3.0	56.7	2.3	12.3	4.691
6	14	648	5.2	11.1		6.4	63.7	1.0	12.5	3.262
7	19	654	6.6	10.4		3.0	63.3	0.5	16.3	3.422
8	24	666	7.1	5.1		2.6	67.0	0.1	18.1	2.855
9	29	674	8.1			2.5	70.9		18.5	2.244
10	34	678	8.2			3.0	71.3		17.5	2.117
11	39	682	8.7			2.0	70.9		18.5	2.238
12	44	684	8.2			2.4	70.8		18.6	2.247
13	49	687	7.9			5.0	72.3		14.9	1.807
14	54	688	7.1			2.0	69.9		21.1	2.553
15	59	688	10.6			2.6	72.5		14.3	1.738
16	64	687	15.7			2.0	75.4		6.9	0.835
17	69	688	17.6			2.5	76.9		3.0	0.363
18	74	683	17.8			3.9	78.0		0.3	0.039
19	79	688	15.5			6.4	78.1			
20	84	687	13.7			8.2	78.1			
21	89	684	9.3			12.6	78.1			
22	94	682	9.1			12.8	78.1			
23	99	679	10.0			11.9	78.1			
24	104	675	5.9			16.0	78.1			
25	109	669	6.1			15.8	78.1			

* AT 15°C AND 101.325 KPA

CO_2 calculated as $(0.2805 \times N_2)-(O_2+0.5 \times CO)$

RUN 17 ESTEVAN LIGNITE (AIR CARBON) ~45KPA

SAMPLE NO.	TIME MIN.	TEMP. °C	COMPOSITION IN VOLUME PERCENT							SPECIFIC HEAT MJ/M3 *
			CO2	H2	C2	O2	N2	CH4	CO	
	0	647								
1	2	617	5.9	8.6		5.6	64.6	2.1	13.1	3.455
2	4	636	4.8	11.4		2.2	59.5	2.8	19.3	4.801
3	6	652	4.5	12.0		2.1	58.8	2.7	19.9	4.915
4	8	662	3.6	11.4		1.8	58.4	2.9	21.9	5.147
5	10	666	3.1	12.5		1.7	57.2	2.9	22.6	5.363
6	12	668	4.2	8.0		1.4	61.2	2.2	23.0	4.599
7	17	672	4.3	6.6		1.4	61.3	2.4	23.4	4.551
8	22	694	3.1	13.8		1.8	57.1	2.0	22.2	5.107
9	27	700	2.6	34.0		1.7	43.9	1.7	16.1	6.735
10	32	702	3.3	10.4		2.2	59.4	2.3	22.5	4.847
11	37	703	3.1	33.6		1.1	44.9	0.6	16.8	6.338
12	42	704	4.5	4.5		2.1	65.4		23.5	3.400
13	47	704	4.9			2.2	68.6		24.4	2.351
14	52	703	5.7			1.8	68.9		23.6	2.857
15	57	703	6.4			1.6	69.2		22.8	2.760
16	62	703	7.3			1.6	69.7		21.4	2.583
17	67	703	9.4			1.4	71.0		18.2	2.203
18	72	702	11.0			2.0	72.4		14.7	1.776
19	77	702	15.2			1.3	74.6		8.9	1.075
20	82	701	17.9			1.4	76.4		4.2	0.512
21	87	693	19.6			1.6	77.7		1.1	0.136
22	92	697	18.8			2.9	78.0		0.3	0.036
23	97	695	16.3			5.6	78.1			
24	102	693	14.4			7.5	78.1			
25	112	687	10.0			11.9	78.1			

* AT 15°C AND 101.325 KPA

CO_2 calculated as $(0.2805 \times N_2) - (O_2 + 0.5 \times CO)$

RUN 13 ESTEVAN LIGNITE (AIR STEAM CARBON) ~45KPA

SAMPLE NO.	TIME MIN.	TEMP. °C	COMPOSITION IN VOLUME PERCENT CO2	H2	C2	O2	N2	CH4	CO	SPECIFIC HEAT MJ/M3 *
	0	649								
1	5	623	4.2	24.4		5.4	53.2	2.1	10.7	5.061
2	15	630	2.1	54.2		1.1	30.1	1.9	10.6	8.580
3	20	631	2.3	41.9		1.7	38.4	2.3	13.5	7.573
4	25	629	4.5	38.6		1.7	42.4	1.4	11.4	6.607
5	30	627	2.2	40.3		2.2	40.6	0.7	14.1	6.379
6	35	624	2.3	40.0		2.3	41.5	0.5	12.3	6.612
7	40	623	2.3	61.3		1.4	27.0	0.2	7.7	8.453
8	45	622	3.3	53.4		1.2	28.8	0.1	7.2	8.132
9	50	620	10.9	16.8		2.6	62.0		7.8	2.930
10	55	619	7.4	3.9		12.3	74.2		2.2	0.742
11	60	618	11.0	19.6		5.0	61.7		2.6	2.716
12	65	614	14.0			7.7	78.0		0.4	0.042
13	70	612	14.5			7.4	78.1			
14	75	609	12.3			9.6	78.1			
15	80	606	10.0			11.9	78.1			
16	85	602	10.7			11.3	78.1			
17	90	619	10.1			11.8	78.1			
18	95	625	9.1			12.8	78.1			
19	100	627	13.8			8.1	78.1			
20	105	627	8.0			13.9	78.1			

* AT 15°C AND 101.325 KPA

CO_2 calculated as $(0.2805xN_2)-(O_2+0.5xCO)$

RUN 19 ESTEVAN LIGNITE (AIR STEAM CARBON) ~45KPA

SAMPLE NO.	TIME MIN.	TEMP. •C	COMPOSITION IN VOLUME PERCENT CO2	H2	C2	O2	N2	CH4	CO	SPECIFIC HEAT MJ/M3 *
	0	941								
1	5	897		40.2		1.7	30.0	4.9	23.2	9.515
2	15	919		46.9		0.7	22.7	3.3	26.5	10.114
3	20	920		58.9		0.4	19.1	1.4	20.1	10.087
4	25	918		41.7		1.0	28.8	1.1	27.5	8.778
5	30	916		40.5		1.1	31.8	0.7	26.0	8.298
6	35	914		42.2		0.9	32.5	0.3	24.1	8.151
7	40	909	< 0.1	38.5		1.2	40.2		20.0	7.096
8	45	909	10.3	22.9		1.2	56.7		8.8	3.869
9	50	906	14.9	13.1		2.4	66.8		2.9	1.949
10	55	895	10.9	7.9		9.0	71.7		0.4	1.025
11	60	912	6.2			15.7	78.1			
12	65	915	7.6			14.3	78.1			

* AT 15•C AND 101.325 KPA

CO_2 calculated as $(0.2805 \times N_2)-(O_2+0.5 \times CO)$

RUN 20 ESTEVAN LIGNITE (AIR CARBON) ~45KPA

SAMPLE NO.	TIME MIN.	TEMP. °C	COMPOSITION IN VOLUME PERCENT CO2	H2	C2	O2	N2	CH4	CO	SPECIFIC HEAT MJ/M3 *
	0	912								
1	10	927	< 0.1	26.6		3.1	46.7	3.8	19.3	7.064
2	15	939	1.0	23.0		2.2	43.4	3.2	21.2	6.574
3	20	942	0.2	59.0		0.8	26.3	1.0	12.7	9.066
4	25	939	1.0	10.4		1.6	59.1		27.9	4.646
5	30	939	1.8			2.9	67.0		28.4	3.433
6	35	940	1.4			2.5	66.6		29.5	3.574
7	40	943	1.7			1.8	66.3		30.2	3.659
8	45	942	1.4			3.3	67.1		28.2	3.410
9	55	936	1.3			3.2	66.9		28.7	3.469
10	60	938	1.2			3.5	67.1		28.2	3.411
11	65	927	4.2			1.6	67.7		26.5	3.209
12	70	925	10.4			2.1	72.1		15.4	1.867
13	75	920	12.2			2.4	73.4		12.0	1.458
14	80	915	13.2			2.7	74.2		9.8	1.194
15	85	916	16.8			1.7	75.9		5.5	0.673
16	90	913	17.0			3.1	77.0		2.9	0.356
17	95	913	17.0			4.8	78.0		0.2	0.022
18	100	910	20.6			1.2	78.0		0.2	0.019
19	105	917	20.2			1.7	78.1			
20	110	910	19.0			2.6	77.9		0.5	0.056
21	115	911	17.8			4.1	78.1			
22	120	912	15.6			6.3	78.1			

* AT 15°C AND 101.325 KPA

CO_2 calculated as $(0.2805 \times N_2) - (O_2 + 0.5 \times CO)$

RUN 21A ESTEVAN LIGNITE (AIR STEAM CARBON) 2MPA

SAMPLE NO.	TIME MIN.	TEMP. °C	COMPOSITION IN VOLUME PERCENT CO2	H2	C2	O2	N2	CH4	CO	SPECIFIC HEAT MJ/M3 *
	0	671								
1	5	943	3.2	14.9		0.7	53.5	5.5	22.2	6.576
2	10	965		22.2		0.6	45.4	7.4	24.4	8.463
3	15	975	2.3	41.5		0.5	37.7	2.4	15.5	7.335
4	20	1020	4.7	22.2		0.7	51.6	2.7	18.2	5.932
5	25	936	3.9	26.2		0.8	48.6	2.6	18.0	6.362
6	30	923	3.8	28.6		0.6	47.1	2.3	17.7	6.500
7	35	914	3.7	27.0		0.8	48.4	1.9	18.2	6.209
8	40	908	5.0	22.9		0.8	52.2	1.4	17.8	5.454
9	45	904	3.7	22.5		1.0	51.0	2.6	19.1	6.047
10	50	906	4.4	24.1		0.8	50.2	2.7	17.7	6.102
11	55	909	4.2	25.8		0.7	48.9	2.7	17.8	6.299
12	60	914	3.4	35.2		0.8	42.7	2.3	15.7	7.045
13	65	918	3.8	27.4		0.7	47.7	2.5	17.8	6.458
14	70	921	3.8	28.3		0.7	47.2	2.4	17.6	6.496
15	75	939	3.7	28.8		0.7	47.0	2.2	17.7	6.471
16	80	948	3.9	27.0		0.7	48.4	2.1	18.0	6.245
17	85	947	4.1	26.5		0.6	49.0	1.8	17.9	6.081
18	90	940	4.7	24.7		0.6	50.7	1.5	17.9	5.734
19	95	928	5.6	23.9		0.7	52.0	1.2	16.6	5.374
20	100	820	8.4	17.8		0.7	57.8	1.0	14.2	4.273
21	105	668	14.6	7.9		3.6	70.4	0.3	3.1	1.473
22	110	568	15.1	5.7		4.0	72.5	0.2	2.6	1.075

* AT 15°C AND 101.325 KPA

CO_2 calculated as $(0.2805 \times N_2) - (O_2 + 0.5 \times CO)$

RUN 21 ESTEVAN LIGNITE (CARBON AIR STEAM) 2MPA

SAMPLE NO.	TIME MIN.	TEMP. °C	COMPOSITION IN VOLUME PERCENT CO2	H2	C2	O2	N2	CH4	CO	SPECIFIC HEAT MJ/M3 *
	0	671								
1	5	943	7.8	33.2	0.5	3.5	40.7	2.6	11.7	6.800
2	10	965	10.8	21.3	0.6	3.2	42.6	4.1	17.4	6.647
3	15	975	9.3	23.6	1.0	4.0	40.2	5.3	16.1	7.720
4	20	1020	8.5	22.4	0.2	1.7	42.4	5.8	19.0	7.364
5	25	963	7.3	20.2	0.1	1.4	46.0	4.4	20.5	6.699
6	30	923	6.7	17.8	< 0.1	1.3	48.3	4.4	21.4	6.481
7	35	914	9.3	17.7	< 0.1	1.0	49.5	3.1	19.4	5.715
8	40	908	10.5	19.5	< 0.1	1.0	48.5	2.5	18.0	5.536
9	45	904	10.2	23.2	< 0.1	0.9	46.4	2.4	16.9	5.818
10	50	906	11.3	22.5	< 0.1	1.2	45.4	2.4	16.2	5.638
11	55	909	11.2	25.5	< 0.1	1.1	44.5	2.3	15.4	5.864
12	60	914	9.3	36.1	< 0.1	0.8	38.0	2.0	13.2	6.765
13	65	918	9.8	29.4	< 0.1	4.3	44.1	1.4	11.0	5.472
14	70	921	10.3	22.7	< 0.1	5.3	48.9	1.4	11.3	4.698
15	75	939	11.1	22.2	< 0.1	4.5	48.4	1.5	12.2	4.773
16	80	948	11.6	24.4	< 0.1	3.2	46.0	1.5	13.2	5.162
17	85	947	11.1	27.1		2.0	44.3	1.5	14.0	5.553
18	90	940	11.1	26.3		1.3	45.2	1.4	14.7	5.497
19	95	928	8.7	27.0		0.8	47.3	1.2	15.0	5.553
20	100	820	12.1	21.3		0.3	50.7	1.0	14.1	4.678
21	105	668	12.7	23.0		1.3	53.4	0.6	8.9	4.133
22	110	568	13.6	11.3		2.3	63.9	1.0	7.8	2.729

* AT 15°C AND 101.325 KPA

RUN 22 ESTEVAN LIGNITE (CARBON AIR STEAM) 2MPA

SAMPLE NO.	TIME MIN.	TEMP. °C	COMPOSITION IN VOLUME PERCENT CO2	H2	C2	O2	N2	CH4	CO	SPECIFIC HEAT MJ/M3 *
	0	660								
1	5	557	18.1	13.0	0.3	12.0	51.8	2.0	2.9	2.895
2	10	840	20.5	28.3	0.7	2.4	35.0	5.6	7.5	6.385
3	15	845	15.7	31.4	0.6	1.8	32.4	8.0	10.1	8.484
4	20	860	14.5	30.5	0.6	1.2	30.6	10.6	12.0	9.578
5	25	875	13.0	23.9	0.2	1.6	38.3	8.3	14.6	8.016
6	30	889	13.6	24.5	< 0.1	1.2	41.7	5.0	13.9	6.627
7	35	899	14.5	22.4	< 0.1	0.7	43.1	4.2	15.0	6.134
8	40	910	14.5	22.1	< 0.1	0.8	43.6	3.8	15.2	5.985
9	45	922	14.2	21.0	< 0.1	1.1	45.0	3.3	15.4	5.697
10	50	934	10.2	23.8	< 0.1	4.6	47.8	2.1	11.3	5.090
11	55	942	11.7	21.7	< 0.1	1.5	46.4	2.5	16.2	5.562
12	60	954	11.7	17.5	< 0.1	1.4	49.2	2.4	17.8	5.229
13	65	942	11.4	17.3	< 0.1	0.9	49.6	2.1	18.7	5.177
14	70	945	10.8	19.7	< 0.1	0.9	48.6	1.8	18.2	5.231
15	75	947	11.2	18.0	< 0.1	0.7	48.4	1.8	19.8	5.158
16	80	949	11.4	17.2	< 0.1	0.8	50.3	1.5	18.8	4.969
17	85	948	11.6	16.9	< 0.1	0.7	50.6	1.3	18.7	4.845
18	90	946	11.7	16.9		0.7	51.2	1.1	18.3	4.715
19	95	939	10.6	16.4		0.7	53.5	1.0	17.7	4.526
20	100	934	12.3	13.8		0.7	55.7	0.8	16.7	4.011
21	105	926	12.8	12.6		0.8	58.1	0.7	15.0	3.608
22	110	902	14.3	9.8		0.8	62.7	0.5	11.8	2.836
23	115	612	16.5	6.4		0.9	69.1	0.3	6.8	1.734
24	120	652	6.0	1.4		14.8	76.3	0.2	1.2	0.389

* AT 15°C AND 101.325 KPA

RUN23 ESTEVAN LIGNITE (CARBON AIR STEAM) 2MPA

SAMPLE NO.	TIME MIN.	TEMP. °C	COMPOSITION IN VOLUME PERCENT CO2	H2	C2	O2	N2	CH4	CO	SPECIFIC HEAT MJ/M3 *
	0	662								
1	5	383	15.9	22.6	< 0.1	0.6	43.2	3.3	14.5	5.767
2	10	668	1.1			19.3	78.4	0.1	1.0	0.173
3	15	751	5.9	46.3	0.8	7.5	35.7	0.8	3.0	6.830
4	20	753	22.1	22.9	0.8	8.8	37.6	4.9	2.9	5.507
5	25	763	22.5	34.3	1.2	3.3	27.0	7.8	3.9	8.429
6	30	772	19.3	20.0	1.0	6.7	42.1	7.3	3.6	6.317
7	35	786	25.1	30.8	1.2	0.6	26.6	10.8	4.8	9.245
8	40	738	19.4	34.7	1.1	0.7	22.5	17.6	4.0	12.140
9	45	811	22.7	24.7	1.2	2.0	32.1	12.3	5.0	9.092
10	50	324	19.4	33.9	1.1	1.5	27.0	12.1	4.9	10.054
11	55	844	15.8	25.0	0.9	5.4	38.1	10.7	4.2	8.204
12	60	863	19.3	34.0	1.1	0.4	24.5	14.6	6.2	11.129
13	65	906	17.6	34.9	0.5	0.4	28.9	10.5	7.3	9.447
14	70	861	19.2	31.2	0.3	0.4	32.4	8.5	8.0	8.202
15	75	831	18.0	31.6	0.1	0.4	33.8	5.2	11.0	7.221
16	80	810	17.1	29.6	0.1	0.5	35.1	4.7	12.9	7.026
17	85	798	16.1	27.7	< 0.1	0.5	37.0	4.5	14.2	6.844
18	90	786	15.0	29.7	< 0.1	0.6	37.1	3.8	13.8	6.763
19	95	772	13.5	26.8	< 0.1	0.6	40.1	4.0	15.0	6.624
20	100	760	14.2	29.7	0.1	0.5	37.9	3.4	14.1	6.706
21	105	751	15.2	24.6	< 0.1	0.5	41.4	3.2	15.1	6.076
22	110	741	15.0	24.6	< 0.1	0.5	41.9	3.0	15.0	5.962
23	115	732	14.6	25.4	0.1	0.5	42.1	2.7	14.5	5.976
24	120	725	14.7	23.7	< 0.1	0.5	43.5	2.4	15.2	5.650
25	125	720	14.6	24.9	0.2	0.5	42.6	2.2	15.1	5.789
26	135	709	14.4	23.4	< 0.1	0.5	44.4	1.9	15.3	5.455
27	145	694	14.5	23.9	< 0.1	0.6	44.6	1.8	14.7	5.374
28	155	683	14.9	20.4	0.2	0.6	49.3	1.5	13.1	4.791
29	165	672	15.5	15.4	< 0.1	0.7	59.8	0.8	7.7	3.141
30	175	662	13.8	3.1	< 0.1	6.1	75.2	0.3	1.4	0.695
31	190	661	6.3	3.1	< 0.1	15.4	73.9	0.4	1.0	0.652
32	200	659	4.3	1.8	< 0.1	17.3	75.4	0.3	0.9	0.468

* AT 15°C AND 101.325 KPA

RUN 24 ESTEVAN LIGNITE (CARBON AIR STEAM) 4MPA

SAMPLE NO.	TIME MIN.	TEMP. °C	COMPOSITION IN VOLUME PERCENT CO2	H2	C2	O2	N2	CH4	CO	SPECIFIC HEAT MJ/M3 *
	0	656								
1	5	1023	15.2	20.4	0.4	2.1	43.0	4.3	14.6	6.177
2	10	1026	11.6	30.7	0.4	1.0	35.3	5.1	15.9	7.830
3	15	997	11.1	26.2	0.4	1.2	36.1	7.8	17.1	8.520
4	20	1008	9.9	20.9	0.2	1.1	43.8	4.6	19.5	6.770
5	25	1035	7.6	15.0	< 0.1	1.4	51.0	2.8	22.2	5.607
6	30	1059	7.2	12.7		1.3	53.6	1.7	23.5	5.038
7	35	935	6.8	10.9		0.8	55.6	1.0	24.9	4.712
8	40	895	6.2	6.1		0.8	61.7	0.3	24.9	3.870
9	45	872	12.2	1.5		2.0	74.0	0.1	10.1	1.456
10	50	804	9.2			10.3	73.3	< 0.1	2.1	0.279
11	55	734	4.1			16.5	78.7		0.6	0.076
12	60	709	2.8			17.9	78.9		0.4	0.054
13	65	690	1.6			19.0	79.1		0.2	0.027
14	70	677	1.2			19.4	79.2		0.2	0.024
15	75	671	0.8			19.5	79.5		0.2	0.025

* AT 15°C AND 101.325 KPA

RUN 25 ESTEVAN LIGNITE (CARBON AIR STEAM) 4MPA

SAMPLE NO.	TIME MIN.	TEMP. °C	COMPOSITION IN VOLUME PERCENT CO2	H2	C2	O2	N2	CH4	CO	SPECIFIC HEAT MJ/M3 *
	0	656								
1	5	820	5.4			18.3	76.3			
2	10	883	27.4	23.8	0.9	2.6	31.6	7.1	6.5	7.050
3	15	904	19.6	23.3	0.8	0.8	35.0	8.9	11.5	8.147
4	20	965	16.3	24.8	0.7	0.7	31.6	12.1	13.2	9.695
5	25	1000	14.5	23.2	0.4	0.6	36.3	10.9	14.0	8.960
6	30	1026	14.3	18.4	0.2	0.7	44.1	7.8	14.4	7.112
7	35	1017	14.1	17.7	0.2	0.7	46.2	6.7	14.5	6.557
8	40	1004	12.4	11.9	< 0.1	1.0	54.4	4.3	15.9	5.062
9	45	971	11.0	8.9	< 0.1	1.0	59.1	2.8	17.1	4.274
10	50	946	9.4	6.1		1.0	63.4	1.5	18.6	3.557
11	55	935	9.2	5.7		1.0	63.3	1.2	19.5	3.519
12	60	929	9.6	7.2		1.0	61.3	1.4	19.5	3.774
13	65	931	10.4	10.3		0.9	57.9	1.6	18.9	4.157
14	70	934	10.5	10.8		1.0	57.5	1.6	18.6	4.189
15	75	922	10.8	11.0		1.0	57.7	1.4	18.2	4.063
16	80	900	10.7	10.5		1.1	58.9	1.1	17.6	3.829
17	85	872	11.2	9.0		1.0	60.9	0.8	17.0	3.481
18	90	771	12.7	8.4		1.0	63.3	0.6	14.0	2.956
19	95	698	14.3	7.3		1.0	66.5	0.5	10.5	2.338
20	100	684	15.8	7.4		1.3	69.7	0.3	5.5	1.683
21	105	671	11.4	2.0		8.1	76.1	0.1	2.3	0.574
22	110	658	7.1			13.5	78.0	0.1	1.3	0.136
23	115	647	3.8			17.1	78.4	< 0.1	0.6	0.100
24	120	643	3.0			18.0	78.5	< 0.1	0.4	0.076

* AT 15°C AND 101.325 KPA

RUN 26 ESTEVAN LIGNITE (CARBON AIR STEAM) 2MPA

SAMPLE NO.	TIME MIN.	TEMP. °C	COMPOSITION IN VOLUME PERCENT CO2	H2	C2	O2	N2	CH4	CO	SPECIFIC HEAT MJ/M3 *
	0	655								
1	5	771	21.2	31.3	0.6	0.7	31.1	5.2	9.8	7.388
2	10	814	16.4	41.6	0.5	0.4	23.3	6.4	11.3	9.226
3	15	813	17.5	34.1	0.5	0.3	25.7	9.5	12.3	9.559
4	20	857	17.0	34.3	0.4	0.4	27.3	8.7	12.0	9.172
5	25	864	17.1	32.3	< 0.1	0.5	35.0	4.2	10.9	6.902
6	30	865	16.5	30.2	< 0.1	0.5	37.3	3.8	11.7	6.576
7	35	863	15.4	27.6	< 0.1	0.6	40.6	3.0	12.8	6.104
8	40	855	14.6	21.5	< 0.1	0.6	45.4	2.7	15.2	5.504
9	45	844	13.7	19.4	< 0.1	0.7	48.0	2.5	15.7	5.245
10	50	830	13.4	18.0	< 0.1	0.6	49.5	2.0	16.4	4.939
11	55	810	13.3	17.4		0.6	50.2	1.7	16.7	4.804
12	60	796	12.7	24.4		0.6	45.9	1.6	14.9	5.378
13	65	786	14.1	18.8		0.7	50.2	1.3	14.9	4.604
14	70	778	15.0	16.2		0.7	54.5	1.0	12.7	3.882
15	75	768	16.0	12.6		0.8	60.4	0.7	9.5	2.982
16	80	765	17.2	8.1		0.9	67.1	0.5	6.2	1.923
17	85	746	18.5	3.4		1.4	74.1	0.2	2.3	0.783
18	90	685	15.0	1.7		5.7	76.5	0.1	1.0	0.373
19	95	671	10.5			10.6	78.1	0.1	0.6	0.114
20	100	662	5.0			16.6	77.9	< 0.1	0.5	0.082
21	105	654	3.3			18.2	78.1	< 0.1	0.3	0.067

* AT 15°C AND 101.325 KPA

RUN 21 ESTEVAN LIGNITE (CARBON AIR STEAM) 6MPA

SAMPLE NO.	TIME MIN.	TEMP. •C	COMPOSITION IN VOLUME PERCENT CO2	H2	C2	O2	N2	CH4	CO	SPECIFIC HEAT MJ/M3 *
	0	653								
1	5	454	24.3			13.1	62.6			
2	10	862	28.9			11.5	59.6			
3	15	917	29.9			9.3	60.8			
4	20	950	28.4			16.1	55.5			
5	25	981	56.0		1.7	3.5	15.6	16.8	5.4	8.188
6	30	838	55.1		1.9	2.5	25.5	10.3	4.8	5.772

* AT 15•C AND 101.325 KPA

RUN 28 ESTEVAN LIGNITE (CARBON AIR STEAM) 6MPA

SAMPLE NO.	TIME MIN.	TEMP. °C	COMPOSITION IN VOLUME PERCENT CO2	H2	C2	O2	N2	CH4	CO	SPECIFIC HEAT MJ/M3 *
	0	657								
1	5	547	9.0	50.9	7.1	2.0	25.7		5.2	11.549
2	10	876	7.9			14.6	77.5			
3	15	922	8.2			17.3	74.5			
4	20	950	24.6	43.8	2.1	3.9	19.6	4.1	1.9	8.514
5	25	988	27.6	29.6	1.4	1.1	24.8	9.5	6.0	8.911
6	30	997	20.6	23.0	1.2	0.9	36.5	11.2	6.6	8.674
7	35	996	17.2	22.0	1.1	0.6	38.7	12.4	8.0	9.119
8	40	1003	12.1	41.9	1.1	0.7	28.9	8.6	6.7	9.907
9	45	987	12.3	13.6	0.5	0.8	50.0	8.7	14.1	7.005
10	50	952	10.6	12.5	0.3	0.8	54.4	5.5	16.0	5.750
11	55	925	9.6	6.0	0.1	0.9	61.6	2.6	19.2	4.131
12	60	908	8.2	4.4	< 0.1	0.9	64.2	1.8	20.5	3.732
13	65	904	8.2	6.1	0.1	0.9	62.2	2.3	20.2	4.154
14	70	896	7.2	5.4	< 0.1	1.0	63.2	1.1	22.0	3.772
15	75	854	7.5	6.1	< 0.1	1.0	61.6	1.5	22.3	4.032
16	80	828	7.0	12.8	< 0.1	0.9	56.4	1.1	21.8	4.629
17	85	737	6.6	18.1	< 0.1	0.8	52.8	0.9	20.7	5.061
18	90	679	7.2	7.9	< 0.1	0.9	59.5	0.9	23.6	4.171
19	95	702	7.5	7.5	< 0.1	0.9	59.7	0.8	23.6	4.082
20	100	684	8.1	7.5	< 0.1	0.9	60.9	0.9	21.7	3.912
21	105	679	12.0	2.7		2.3	71.0	0.4	11.6	1.873
22	110	672	10.4	3.0		6.8	74.1	0.2	5.5	1.101
23	115	664	7.5	0.7		11.5	77.5	0.1	2.7	0.450
24	120	656	4.4			15.3	79.1	< 0.1	1.2	0.170
25	125	649	3.4			16.5	79.3		0.9	0.103
26	135	633	2.5			17.8	79.1	< 0.1	0.6	0.087

* AT 15°C AND 101.325 KPA

RUN 29 ESTEVAN LIGNITE (CARBON AIR STEAM) 6MPA

SAMPLE NO.	TIME MIN.	TEMP. •C	COMPOSITION IN VOLUME PERCENT CO2	H2	C2	O2	N2	CH4	CO	SPECIFIC HEAT MJ/M3 *
	0	657								
1	10	857	32.2			4.4	51.2	1.2	11.0	1.785
2	15	906	46.8	28.1	1.2	2.0	10.4	6.3	5.1	7.279
3	20	931	35.7	27.7	1.8	0.9	18.0	11.3	4.6	9.436
4	25	958	26.4	28.0	1.5	1.3	27.4	10.9	4.4	9.097
5	30	959	26.9	26.6	1.5	1.4	28.0	11.1	4.5	9.025
6	35	969	19.4	14.1	1.2	0.6	41.6	15.8	7.4	9.390
7	40	960	16.5	14.7	0.9	0.6	43.8	14.6	8.8	9.029
8	45	954	14.5	12.5	0.7	0.6	48.6	11.8	11.3	7.816
9	50	941	12.1	14.6	0.4	0.8	51.6	8.2	12.2	6.677
10	55	936	10.9	6.5	0.2	1.0	60.8	4.8	15.8	4.697
11	60	927	9.8	4.6	0.1	0.9	64.2	2.7	17.6	3.809
12	65	922	9.2	4.1	< 0.1	0.9	65.3	2.1	18.4	3.652
13	70	904	8.8	4.0	< 0.1	0.9	65.9	1.3	19.0	3.340
14	75	898	8.4	1.6	< 0.1	1.1	67.9	1.0	20.0	3.005
15	80	898	8.3	2.6	< 0.1	1.1	66.7	0.9	20.3	3.121
16	85	895	8.4	2.6	< 0.1	1.2	65.6	1.1	21.0	3.302
17	90	893	8.6	4.4	< 0.1	1.0	64.0	1.2	20.8	3.530
18	95	881	8.7	5.1	< 0.1	0.9	63.1	1.3	20.9	3.560
19	100	868	8.5	5.3		0.9	62.8	1.3	21.2	3.716
20	105	855	8.5	5.5		1.2	62.6	1.2	21.0	3.662
21	110	825	8.8	5.8		1.0	62.0	1.1	21.2	3.703
22	120	705	9.8	11.3		0.9	56.6	1.3	20.1	4.313
23	130	658	12.1	15.3		0.9	53.0	1.3	17.4	4.465
24	135	635	13.6	13.9		1.6	58.1	1.0	11.7	3.511

* AT 15•C AND 101.325 KPA

RUN 30 ESTEVAN LIGNITE (PYROLYSIS) 2MPA

SAMPLE NO.	TIME MIN.	TEMP. °C	COMPOSITION IN VOLUME PERCENT CO2	H2	C2	O2	N2	CH4	CO	SPECIFIC HEAT MJ/M3 *
	0	817								
1	5	680	23.1	60.4	0.9	0.2	4.6	6.7	4.0	10.972
2	10	795	13.7	35.1	0.8	0.3	38.9	8.2	3.1	8.264
3	15	801	3.9	33.6	0.7	0.3	46.3	7.2	3.0	7.676
4	20	804	6.7	28.8	0.8	0.2	52.2	7.9	3.5	7.463
5	25	805	3.9	21.4	0.5	0.1	63.0	7.4	3.7	6.191
6	30	807	1.8	13.5	0.2	0.2	77.8	4.0	2.4	3.593
7	35	808	1.0	8.5	< 0.1	< 0.1	87.7	1.7	1.0	1.831
8	40	809	0.7	5.5	< 0.1	0.1	92.4	0.7	0.5	1.007
9	45	810	0.6	3.7	< 0.1	0.2	94.9	0.4	0.1	0.616
10	50	811	0.5	3.0	< 0.1	0.2	95.9	0.2	0.2	0.483
11	55	811	0.5	3.2	< 0.1	0.1	95.7	0.2	0.2	0.518
12	60	812	0.4	3.0	< 0.1	0.1	96.2	0.2	0.1	0.454
13	65	811	0.4	1.4		0.1	97.6	0.3	0.1	0.317
14	70	811	0.4	1.3		0.3	97.7	0.1	0.1	0.223

* AT 15°C AND 101.325 KPA

RUN 31 ESTEVAN LIGNITE (CARBON AIR STEAM) ~150KPA

SAMPLE NO.	TIME MIN.	TEMP. °C	COMPOSITION IN VOLUME PERCENT CO2	H2	C2	O2	N2	CH4	CO	SPECIFIC HEAT MJ/M3 *
	0	678								
1	10	667	17.0	37.7	0.4	5.3	31.6	4.5	3.4	7.022
2	15	674	19.7	51.7	0.3	1.2	19.0	4.0	4.2	8.492
3	20	664	20.5	46.2		0.9	26.7	1.3	4.4	6.649
4	25	662	20.2	44.5		1.5	28.8	1.1	4.0	6.319
5	30	670	2.6	55.1		1.2	34.9	0.6	5.6	7.607
6	35	656	14.6	66.6		1.1	17.7			8.092
7	40	643	23.1	59.1		0.6	13.6	0.5	3.1	7.757
8	45	644	23.9	64.9		0.6	8.1	0.4	2.1	8.282
9	50	673	20.8	45.5		1.0	26.9	0.8	5.0	6.432
10	55	705	14.8	19.7		2.4	51.6	0.5	11.0	3.930
11	60	710	10.8	19.0		1.9	56.2	0.5	11.7	3.909
12	65	639	1.2	5.4	0.2	15.7	73.4	0.1	4.0	1.328
13	70	685	20.2	29.0		1.8	45.6	0.1	3.2	3.982
14	75	645	3.3			19.2	77.4			
15	80	637	1.5			19.3	79.3			
16	85	636	1.0			19.4	79.7			

* AT 15°C AND 101.325 KPA

Appendix 3 ACCUMULATED GASEOUS COMPONENTS

The total number of moles produced since the start of the reaction up to and including each sampling points are given for reactions 12 through 31.

The calculations are based on either supplied air volume or produced gas volume as described in Section 6.1. The amount of CO_2 in experiments 12 through 21 A was calculated on the basis of available oxygen as $(0.2805 \times N_2) - (O_2 \times 0.5 \times CO)$. For both methods the composition of the product gas was taken as the average of the composition between two sequential samples and assumed to be constant during the time interval between these samples.

BASED ON SUPPLIED AIR VOLUME

RUN 12   ESTEVAN LIGNITE   (AIR CARBON)   ~45KPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*
	0	718										
1	5	670		30.22		0.27	2.02	0.28	0.93	15	93	61
2	10	742	0.01	34.50		0.33	4.03	0.51	1.96	30	209	122
3	15	771	0.02	37.86		0.40	6.05	0.76	2.97	45	302	183
4	20	780	0.02	48.94		0.59	8.06	0.93	3.88	58	388	244
5	25	784	0.10	51.07		0.65	10.08	0.93	4.75	69	461	305
6	30	786	0.21	51.21		0.68	12.09	0.93	5.61	81	530	366
7	35	788	0.30	53.66		0.73	14.11	0.93	6.46	92	595	427
8	40	788	0.40	55.91		0.78	16.12	0.93	7.28	103	657	488
9	45	788	0.52	57.23		0.81	18.14	0.93	8.10	115	725	549
	50	788	0.64	59.10		0.85	20.15	0.93	8.92	126	789	610
11	55	788	0.74	61.65		0.91	22.17	0.93	9.73	137	853	671
12	60	783	0.86	63.49		0.97	24.18	0.93	10.52	148	917	732
13	65	788	1.00	63.49		1.00	26.20	0.93	11.29	159	980	793
14	70	788	1.16	63.55		1.03	28.21	0.93	12.04	170	1043	854
15	75	788	1.30	65.47		1.09	30.23	0.93	12.77	180	1107	915
16	80	787	1.54	67.18		1.15	32.24	0.93	13.31	189	1169	976
17	85	785	1.79	67.18		1.18	34.26	0.93	13.87	199	1231	1037
18	90	785	2.05	67.18		1.21	36.27	0.93	14.42	209	1293	1098
19	95	783	2.33	67.18		1.26	38.29	0.93	14.89	218	1354	1159
20	100	783	2.65	67.18		1.32	40.30	0.93	15.26	226	1412	1220
21	105	782	3.01	67.18		1.35	42.32	0.93	15.61	235	1470	1281
22	110	780	3.39	67.18		1.38	44.33	0.93	15.91	243	1527	1342
23	115	777	3.83	67.18		1.41	46.35	0.93	16.11	250	1582	1403
24	120	775	4.32	67.18		1.45	48.36	0.93	16.20	257	1636	1465

* AT 15°C AND 101.325 KPA

CO_2 calculated as $(0.2805 \times N_2)-(O_2+0.5 \times CO)$

BASED ON PRODUCED GAS VOLUME

RUN 12 ESTEVAN LIGNITE (AIR CARBON) ~45KPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*
	0	718										
1	5	670		1.77		0.02	0.12	0.02	0.05	1	93	61
2	10	742	0.01	4.51		0.05	1.41	0.17	0.71	11	209	122
3	15	771	0.01	6.48		0.10	2.59	0.31	1.30	20	302	183
4	20	780	0.01	9.29		0.15	3.10	0.35	1.53	23	388	244
5	25	784	0.06	10.56		0.18	4.30	0.36	2.05	30	461	305
6	30	786	0.16	10.70		0.21	6.15	0.36	2.85	40	530	366
7	35	788	0.20	11.93		0.23	7.17	0.36	3.27	46	595	427
8	40	788	0.26	13.07		0.26	8.18	0.36	3.69	52	657	488
9	45	788	0.34	13.34		0.28	9.52	0.36	4.23	59	725	549
10	50	788	0.40	14.99		0.30	10.65	0.36	4.69	65	789	610
11	55	788	0.45	16.23		0.33	11.83	0.36	5.09	71	853	671
12	60	788	0.52	17.27		0.36	12.77	0.36	5.53	77	917	732
13	65	788	0.65	17.27		0.39	14.58	0.36	6.23	87	980	793
14	70	788	0.79	17.32		0.42	16.37	0.36	6.89	96	1043	854
15	75	788	0.86	18.37		0.45	17.48	0.36	7.30	102	1107	915
16	80	787	1.00	19.37		0.48	18.65	0.36	7.61	108	1169	976
17	85	785	1.24	19.37		0.51	20.50	0.36	8.12	117	1231	1037
18	90	785	1.47	19.37		0.54	22.33	0.36	8.62	125	1293	1098
19	95	783	1.73	19.37		0.59	24.18	0.36	9.05	134	1354	1159
20	100	783	2.02	19.37		0.64	25.99	0.36	9.33	141	1412	1220
21	105	782	2.34	19.37		0.67	27.78	0.36	9.70	149	1470	1281
22	110	780	2.67	19.37		0.70	29.54	0.36	9.96	156	1527	1342
23	115	777	3.05	19.37		0.73	31.31	0.36	10.14	163	1582	1403
24	120	775	3.47	19.37		0.75	33.05	0.36	10.21	169	1636	1465

* AT 15°C AND 101.325 KPA

CO_2 calculated as $(0.2805 \times N_2)-(O_2+0.5 \times CO)$

BASED ON SUPPLIED AIR VOLUME

RUN 13   ESTEVAN LIGNITE   (AIR CARBON)   ~45KPA

SAMPLE NO.	TIME MIN.	TEMP. •C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*
	0	615										
1	5	627	0.12	0.70		0.06	2.02	0.18	0.76	13	91	61
2	10	687	0.21	2.94		0.17	4.03	0.35	1.54	25	187	122
3	15	712	0.22	8.47		0.34	6.05	0.49	2.37	37	277	183
4	20	719	0.31	10.46		0.39	8.06	0.60	3.22	49	364	244
5	25	721	0.39	12.86		0.46	10.08	0.67	4.06	61	442	305
6	30	723	0.44	20.12		0.60	12.09	0.68	4.80	71	513	366
7	35	725	0.58	24.39		0.65	14.11	0.68	5.54	82	580	427
8	40	728	0.73	27.39		0.69	16.12	0.68	6.29	92	646	488
9	45	728	0.83	31.20		0.80	18.14	0.68	7.01	102	713	549
10	50	730	0.84	32.46		1.04	20.15	0.68	7.63	110	777	610
11	55	730	0.91	33.43		1.21	22.17	0.68	8.35	119	841	671
12	60	730	1.11	36.14		1.24	24.18	0.68	9.01	130	905	732
13	65	730	1.34	37.02		1.27	26.20	0.68	9.63	140	968	793
14	70	730	1.58	37.67		1.31	28.21	0.68	10.21	150	1031	854
15	75	729	1.72	38.31		1.48	30.23	0.68	10.72	157	1092	915
16	80	729	1.93	38.31		1.61	32.24	0.68	11.15	165	1153	976
17	85	728	2.28	38.31		1.65	34.26	0.68	11.50	174	1212	1037
18	90	728	2.66	38.31		1.69	36.27	0.68	11.79	182	1271	1098
19	95	726	3.06	38.31		1.75	38.29	0.68	12.02	189	1329	1159
20	100	725	3.49	38.31		1.80	40.30	0.68	12.18	196	1385	1220
21	105	723	3.95	38.31		1.84	42.32	0.68	12.23	203	1441	1281
22	110	721	4.43	38.31		1.91	44.33	0.68	12.33	209	1496	1342
23	115	720	4.90	38.31		2.01	46.35	0.68	12.33	215	1550	1403
24	120	718	5.36	38.31		2.11	48.36	0.68	12.33	221	1605	1465
25	125	715	5.77	38.31		2.27	50.38	0.68	12.33	225	1660	1526
26	130	712	6.12	38.31		2.43	52.39	0.68	12.33	230	1715	1587
27	135	703	6.44	38.31		2.73	54.41	0.68	12.33	233	1770	1648
28	140	705	6.72	38.31		3.01	56.42	0.68	12.33	237	1825	1709
29	145	699	6.96	38.31		3.33	58.44	0.68	12.33	240	1880	1770
30	150	695	7.18	38.31		3.69	60.45	0.68	12.33	242	1935	1831
31	155	691	7.37	38.31		4.06	62.47	0.68	12.33	245	1993	1892
32	160	688	7.53	38.31		4.46	64.48	0.68	12.33	247	2046	1953
33	165	685	7.68	38.31		4.88	66.50	0.68	12.33	248	2101	2014

* AT 15•C AND 101.325 KPA

CO_2 calculated as $(0.2805 \times N_2) - (O_2 + 0.5 \times CO)$

BASED ON PRODUCED GAS VOLUME

RUN 13 ESTEVAN LIGNITE (AIR CARBON) ~45KPA

SAMPLE NO.	TIME MIN.	TEMP. •C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*
	0	615										
1	5	627	0.06	0.35		0.03	1:01	0.09	0.38	6	91	61
2	10	687	0.13	2.03		0.11	2.52	0.22	0.97	16	187	122
3	15	712	0.13	4.46		0.18	3.41	0.28	1.33	21	277	183
4	20	719	0.19	5.90		0.23	4.86	0.36	1.95	30	364	244
5	25	721	0.24	7.35		0.27	6.08	0.40	2.45	37	442	305
6	30	723	0.26	9.46		0.31	6.67	0.40	2.67	40	513	366
7	35	725	0.31	11.15		0.33	7.46	0.40	2.96	44	580	427
8	40	728	0.38	12.56		0.35	8.41	0.40	3.31	49	646	488
9	45	728	0.42	14.14		0.39	9.25	0.40	3.61	53	713	549
10	50	730	0.43	14.96		0.54	10.55	0.40	4.05	59	777	610
11	55	730	0.48	15.64		0.67	11.96	0.40	4.51	65	841	671
12	60	730	0.58	15.94		0.69	12.93	0.40	4.83	70	905	732
13	65	730	0.74	17.57		0.70	14.36	0.40	5.27	77	968	793
14	70	730	0.92	18.05		0.73	15.87	0.40	5.70	84	1031	854
15	75	729	1.02	18.53		0.86	17.38	0.40	6.08	90	1092	915
16	80	729	1.22	18.53		0.98	19.24	0.40	6.48	97	1153	976
17	85	728	1.54	18.53		1.01	21.07	0.40	6.80	105	1212	1037
18	90	728	1.88	18.53		1.06	22.89	0.40	7.07	112	1271	1098
19	95	726	2.24	18.53		1.11	24.73	0.40	7.27	119	1329	1159
20	100	725	2.63	18.53		1.15	26.53	0.40	7.41	125	1385	1220
21	105	723	3.05	18.53		1.19	28.35	0.40	7.52	132	1441	1281
22	110	721	3.47	18.53		1.25	30.15	0.40	7.55	137	1496	1342
23	115	720	3.89	18.53		1.34	31.93	0.40	7.55	142	1550	1403
24	120	718	4.30	18.53		1.43	33.74	0.40	7.55	147	1605	1465
25	125	715	4.67	18.53		1.57	35.54	0.40	7.55	152	1660	1526
26	130	712	4.98	18.53		1.76	37.36	0.40	7.55	155	1715	1587
27	135	708	5.27	18.53		1.99	39.18	0.40	7.55	159	1770	1648
28	140	705	5.53	18.53		2.24	40.99	0.40	7.55	162	1825	1709
29	145	699	5.74	18.53		2.53	42.81	0.40	7.55	164	1880	1770
30	150	695	5.94	18.53		2.85	44.63	0.40	7.55	167	1935	1831
31	155	691	6.12	18.53		3.21	46.55	0.40	7.55	169	1993	1892
32	160	688	6.26	18.53		3.55	48.30	0.40	7.55	171	2046	1953
33	165	685	6.39	18.53		3.93	50.11	0.40	7.55	172	2101	2014

* AT 15•C AND 101.325 KPA

CO_2 calculated as $(0.2805xN_2)-(O_2+0.5xCO)$

BASED ON SUPPLIED AIR VOLUME

RUN 14 ESTEVAN LIGNITE (AIR CARBON) ~45KPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*
	0	765										
1	5	726		1.21		0.08	2.02	0.39	1.12	18	113	61
2	10	766		2.48		0.21	4.03	0.70	2.21	35	212	122
3	15	787		3.46		0.33	6.05	0.86	3.23	49	310	183
4	20	793	0.01	5.04		0.39	8.06	0.91	4.22	62	393	244
5	25	795	0.06	7.76		0.46	10.08	0.91	5.11	73	464	305
6	30	797	0.11	8.74		0.56	12.09	0.91	5.96	84	532	366
7	35	800	0.17	8.82		0.63	14.11	0.91	6.82	95	599	427
8	40	801	0.24	8.88		0.71	16.12	0.91	7.65	106	667	488
9	45	803	0.31	8.93		0.80	18.14	0.91	8.48	116	733	549
10	50	805	0.35	8.99		0.89	20.15	0.91	9.33	127	800	610
11	55	806	0.38	9.02		1.03	22.17	0.91	10.15	137	866	671
12	60	808	0.39	9.02		1.18	24.18	0.91	10.95	147	933	732
13	65	810	0.44	9.02		1.29	26.20	0.91	11.77	157	999	793
14	70	810	0.53	9.02		1.38	28.21	0.91	12.56	168	1064	854
15	75	812	0.63	9.02		1.45	30.23	0.91	13.33	178	1130	915
16	80	812	0.74	9.02		1.52	32.24	0.91	14.09	189	1196	976
17	84	812	0.80	9.02		1.62	33.85	0.91	14.68	197	1261	1025
18	89	813	0.91	9.02		1.74	35.87	0.91	15.36	206	1325	1086
19	94	814	1.07	9.02		1.82	37.88	0.91	16.01	216	1389	1147
20	99	814	1.26	9.02		1.91	39.90	0.91	16.58	225	1452	1208
21	104	813	1.52	9.02		1.99	41.91	0.91	17.02	233	1513	1269
22	109	809	1.86	9.02		2.09	43.93	0.91	17.27	241	1570	1330
23	114	805	2.26	9.02		2.21	45.94	0.91	17.38	247	1624	1391
24	119	805	2.65	9.02		2.36	47.96	0.91	17.41	252	1676	1452
25	124	802	3.05	9.02		2.53	49.97	0.91	17.41	257	1729	1513
26	129	800	3.47	9.02		2.67	51.99	0.91	17.41	262	1776	1574
27	134	795	3.84	9.02		2.87	54.00	0.91	17.41	266	1826	1635
28	139	784	4.10	9.02		3.17	56.02	0.91	17.41	269	1878	1696
29	144	774	4.30	9.02		3.54	58.03	0.91	17.41	271	1930	1757
30	149	767	4.46	9.02		3.95	60.05	0.91	17.41	273	1983	1818
31	154	761	4.60	9.02		4.37	62.06	0.91	17.41	275	2036	1879
32	159	755	4.72	9.02		4.81	64.08	0.91	17.41	277	2090	1940
33	164	749	4.84	9.02		5.27	66.09	0.91	17.41	278	2144	2001
34	169	745	4.91	9.02		5.76	68.11	0.91	17.41	279	2197	2063

* AT 15°C AND 101.325 KPA

CO_2 calculated as $(0.2805 \times N_2) - (O_2 + 0.5 \times CO)$

BASED ON PRODUCED GAS VOLUME

RUN 14   ESTEVAN LIGNITE   (AIR CARBON)   ~45KPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*
	0	765										
1	5	726		0.60		0.04	1.00	0.19	0.55	9	113	61
2	10	766		1.71		0.15	2.77	0.46	1.51	24	212	122
3	15	787		2.66		0.27	4.70	0.62	2.49	37	310	183
4	20	793	0.01	3.83		0.31	6.20	0.66	3.23	47	393	244
5	25	795	0.04	5.24		0.35	7.24	0.66	3.69	53	464	305
6	30	797	0.07	5.95		0.42	8.71	0.66	4.30	60	532	366
7	35	800	0.12	6.02		0.49	10.57	0.66	5.11	71	599	427
8	40	801	0.19	6.08		0.56	12.44	0.66	5.88	81	667	488
9	45	803	0.25	6.12		0.64	14.31	0.66	6.65	91	733	549
10	50	805	0.30	6.18		0.73	16.17	0.66	7.42	100	800	610
11	55	806	0.32	6.21		0.85	18.03	0.66	8.18	110	866	671
12	60	808	0.33	6.21		1.00	19.93	0.66	8.94	119	933	732
13	65	810	0.37	6.21		1.10	21.81	0.66	9.70	129	999	793
14	70	810	0.46	6.21		1.18	23.69	0.66	10.44	139	1064	854
15	75	812	0.56	6.21		1.25	25.59	0.66	11.16	148	1130	915
16	80	812	0.66	6.21		1.32	27.47	0.66	11.88	158	1196	976
17	84	812	0.73	6.21		1.44	29.34	0.66	12.56	167	1261	1025
18	89	813	0.82	6.21		1.55	31.21	0.66	13.19	176	1325	1066
19	94	814	0.98	6.21		1.62	33.09	0.66	13.73	185	1389	1147
20	99	814	1.15	6.21		1.70	34.97	0.66	14.33	194	1452	1208
21	104	813	1.39	6.21		1.78	36.82	0.66	14.73	201	1513	1269
22	109	809	1.70	6.21		1.87	38.61	0.66	14.95	208	1570	1330
23	114	805	2.04	6.21		1.97	40.36	0.66	15.05	213	1624	1391
24	119	805	2.38	6.21		2.10	42.07	0.66	15.07	217	1676	1452
25	124	802	2.72	6.21		2.24	43.82	0.66	15.07	221	1729	1513
26	129	800	3.05	6.21		2.35	45.39	0.66	15.07	225	1776	1574
27	134	795	3.35	6.21		2.52	47.04	0.66	15.07	229	1826	1635
28	139	784	3.57	6.21		2.77	48.74	0.66	15.07	232	1878	1696
29	144	774	3.74	6.21		3.09	50.48	0.66	15.07	234	1930	1757
30	149	767	3.88	6.21		3.44	52.22	0.66	15.07	235	1983	1818
31	154	761	4.00	6.21		3.81	53.98	0.66	15.07	237	2036	1879
32	159	755	4.11	6.21		4.20	55.74	0.66	15.07	238	2090	1940
33	164	749	4.21	6.21		4.60	57.52	0.66	15.07	239	2144	2001
34	169	745	4.28	6.21		5.03	59.30	0.66	15.07	240	2197	2063

* AT 15°C AND 101.325 KPA

CO_2 calculated as $(0.2805xN_2)-(O_2+0.5xCO)$

BASED ON SUPPLIED AIR VOLUME

RUN 15 ESTEVAN LIGNITE (AIR CARBON) ~45KPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES							CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*
			CO2	H2	C2	O2	N2	CH4	CO			
	0	700										
1	5	679	0.13	5.82		0.03	2.02	0.15	0.80	13	92	61
2	15	712	0.37	26.46		0.13	6.05	0.42	2.40	38	269	183
3	20	728	0.44	34.59		0.21	8.06	0.48	3.23	50	353	244
4	25	733	0.48	35.79		0.30	10.08	0.51	4.10	61	432	305
5	30	738	0.54	35.79		0.37	12.09	0.52	4.96	72	503	366
6	35	740	0.61	36.82		0.44	14.11	0.52	5.81	83	570	427
7	40	743	0.67	39.38		0.53	16.12	0.52	6.64	94	636	488
8	50	747	0.85	40.96		0.64	20.15	0.52	8.33	116	739	610
9	55	750	0.96	40.96		0.71	22.17	0.52	9.10	127	832	671
10	60	751	1.11	40.96		0.78	24.18	0.52	9.77	137	897	732
11	65	754	1.34	40.96		0.84	26.20	0.52	10.33	146	959	793
12	70	753	1.70	40.96		0.90	28.21	0.52	10.63	154	1013	854
13	80	751	2.59	40.96		1.08	32.24	0.52	10.76	166	1127	976
14	85	750	2.99	40.96		1.24	34.26	0.52	10.76	171	1182	1037
15	90	746	3.32	40.96		1.47	36.27	0.52	10.76	175	1239	1098
16	95	735	3.60	40.96		1.76	38.29	0.52	10.76	179	1291	1159
17	100	717	3.78	40.96		2.15	40.30	0.52	10.76	181	1346	1220
18	105	692	3.86	40.96		2.63	42.32	0.52	10.76	182	1401	1281
19	110	682	3.94	40.96		3.12	44.33	0.52	10.76	183	1456	1342
20	115	675	4.00	40.96		3.62	46.35	0.52	10.76	183	1512	1403

* AT 15°C AND 101.325 KPA

CO_2 calculated as $(0.2805 \times N_2) - (O_2 + 0.5 \times CO)$

BASED ON PRODUCED GAS VOLUME

RUN 15 ESTEVAN LIGNITE (AIR CARBON) ~45KPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*
	0	700										
1	5	679	0.03	1.26		0.01	0.44	0.03	0.17	3	92	61
2	15	712	0.09	7.02		0.03	1.56	0.11	0.62	10	269	183
3	20	728	0.12	9.59		0.06	2.20	0.13	0.88	14	353	244
4	25	733	0.15	10.54		0.13	3.79	0.15	1.56	22	432	305
5	30	738	0.21	10.54		0.20	5.79	0.16	2.43	34	503	366
6	35	740	0.26	11.26		0.25	7.20	0.16	3.02	41	570	427
7	40	743	0.29	12:55		0.30	8.22	0.16	3.44	47	636	438
8	50	747	0.39	13.46		0.36	10.54	0.16	4.41	60	739	610
9	55	750	0.53	13.46		0.46	13.22	0.16	5.44	74	832	671
10	60	751	0.68	13.46		0.52	15.10	0.16	6.06	83	897	732
11	65	754	0.89	13.46		0.58	16.95	0.16	6.58	92	959	793
12	70	753	1.22	13.46		0.63	18.81	0.16	6.86	99	1019	854
13	80	751	2.00	13.46		0.78	22.36	0.16	6.97	110	1127	976
14	85	750	2.36	13.46		0.93	24.15	0.16	6.97	114	1182	1037
15	90	746	2.67	13.46		1.15	26.04	0.16	6.97	118	1239	1098
16	95	735	2.91	13.46		1.39	27.76	0.16	6.97	120	1291	1159
17	100	717	3.07	13.46		1.74	29.53	0.16	6.97	122	1346	1220
18	105	692	3.15	13.46		2.18	31.40	0.16	6.97	123	1401	1281
19	110	682	3.21	13.46		2.62	33.22	0.16	6.97	124	1456	1342
20	115	675	3.27	13.46		3.07	35.05	0.16	6.97	125	1512	1403

* AT 15°C AND 101.325 KPA

CO_2 calculated as $(0.2805 \times N_2) - (O_2 + 0.5 \times CO)$

BASED ON SUPPLIED AIR VOLUME

RUN 16 ESTEVAN LIGNITE (AIR CARBON) ~45KPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*
	0	650										
1	4	602	0.16	4.63		0.11	1.27	0.05	0.17	4	42	39
2	6	619	0.26	5.25		0.14	1.91	0.07	0.27	7	69	58
3	8	628	0.36	5.35		0.17	2.54	0.11	0.38	10	97	77
4	10	628	0.44	5.51		0.20	3.18	0.16	0.50	13	126	96
5	12	638	0.52	5.74		0.23	3.82	0.20	0.64	16	157	116
6	14	648	0.58	5.90		0.28	4.45	0.22	0.77	19	184	135
7	19	654	0.73	6.17		0.40	6.04	0.24	1.13	25	281	183
8	24	666	0.90	6.35		0.46	7.63	0.25	1.55	32	315	231
9	29	674	1.07	6.41		0.52	9.22	0.25	1.98	40	375	279
10	34	678	1.26	6.41		0.59	10.81	0.25	2.38	47	434	327
11	39	682	1.49	6.41		0.66	12.82	0.25	2.89	56	492	388
12	44	684	1.68	6.41		0.71	14.41	0.25	3.30	63	550	436
13	49	687	1.86	6.41		0.79	16.00	0.25	3.67	69	609	484
14	54	688	2.03	6.41		0.87	17.59	0.25	4.08	76	667	533
15	59	688	2.23	6.41		0.92	19.18	0.25	4.47	83	724	581
16	64	687	2.51	6.41		0.97	20.77	0.25	4.70	90	778	629
17	69	688	2.86	6.41		1.01	22.36	0.25	4.80	95	831	677
18	74	688	3.22	6.41		1.08	23.95	0.25	4.84	100	882	725
19	79	688	3.56	6.41		1.18	25.54	0.25	4.84	104	933	773
20	84	687	3.96	6.41		1.33	27.13	0.25	4.84	107	985	821
21	89	684	4.09	6.41		1.54	28.72	0.25	4.84	110	1037	870
22	94	682	4.28	6.41		1.80	30.31	0.25	4.84	112	1089	918
23	99	679	4.47	6.41		2.05	31.90	0.25	4.84	115	1141	966
24	104	675	4.63	6.41		2.34	33.49	0.25	4.84	117	1194	1014
25	109	669	4.76	6.41		2.66	35.07	0.25	4.84	118	1246	1062

* AT 15°C AND 101.325 KPA

CO_2 calculated as $(0.2805xN_2)-(O_2+0.5xCO)$

BASED ON PRODUCED GAS VOLUME

RUN 16 ESTEVAN LIGNITE (AIR CARBON) ~45KPA

SAMPLE NO.	TIME MIN.	TEMP. •C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*
	0	650										
1	4	602	0.02	0.65		0.02	0.18	0.01	0.02	1	42	39
2	6	619	0.10	1.12		0.03	0.66	0.03	0.10	3	69	58
3	8	628	0.21	1.23		0.07	1.41	0.07	0.23	6	97	77
4	10	628	0.31	1.41		0.11	2.13	0.13	0.37	10	126	96
5	12	638	0.40	1.67		0.14	2.83	0.13	0.52	13	157	116
6	14	648	0.47	1.84		0.19	3.54	0.20	0.67	16	184	135
7	19	654	0.71	2.28		0.38	6.13	0.23	1.25	26	281	183
8	24	666	0.81	2.39		0.42	7.06	0.23	1.50	30	315	231
9	29	674	1.00	2.46		0.49	8.83	0.23	1.97	38	375	279
10	34	678	1.20	2.46		0.56	10.59	0.23	2.41	46	434	327
11	39	682	1.41	2.46		0.62	12.34	0.23	2.86	54	492	388
12	44	684	1.62	2.46		0.67	14.08	0.23	3.31	62	550	436
13	49	687	1.82	2.46		0.76	15.85	0.23	3.72	69	609	484
14	54	688	2.00	2.46		0.85	17.59	0.23	4.17	77	667	533
15	59	688	2.22	2.46		0.90	19.31	0.23	4.59	85	724	581
16	64	687	2.52	2.46		0.96	21.00	0.23	4.84	91	778	629
17	69	688	2.89	2.46		1.01	22.70	0.23	4.95	97	831	677
18	74	688	3.27	2.46		1.08	24.38	0.23	4.98	102	882	725
19	79	688	3.63	2.46		1.19	26.08	0.23	4.99	106	933	773
20	84	687	3.95	2.46		1.35	27.79	0.23	4.99	110	985	821
21	89	684	4.20	2.46		1.58	29.50	0.23	4.99	113	1037	870
22	94	682	4.41	2.46		1.86	31.22	0.23	4.99	116	1089	918
23	99	679	4.62	2.46		2.13	32.94	0.23	4.99	118	1141	966
24	104	675	4.79	2.46		2.44	34.67	0.23	4.99	120	1194	1014
25	109	669	4.93	2.46		2.79	36.40	0.23	4.99	122	1246	1062

* AT 15•C AND 101.325 KPA

CO_2 calculated as $(0.2805 \times N_2)-(O_2+0.5 \times CO)$

BASED ON SUPPLIED AIR VOLUME

RUN 17 ESTEVAN LIGNITE (AIR CARBON) ~45KPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*
	0	647										
1	2	617	0.06	0.09		0.06	0.64	0.02	0.13	3	25	19
2	4	636	0.11	0.19		0.10	1.29	0.05	0.30	6	54	39
3	6	652	0.17	0.32		0.12	1.93	0.08	0.51	9	84	58
4	8	662	0.21	0.45		0.14	2.57	0.11	0.74	13	115	78
5	10	666	0.25	0.58		0.16	3.22	0.14	0.99	17	145	97
6	12	668	0.29	0.69		0.18	3.86	0.17	1.24	20	178	117
7	17	672	0.40	0.88		0.21	5.47	0.23	1.84	30	251	166
8	22	694	0.50	1.16		0.26	7.08	0.29	2.46	39	327	214
9	27	700	0.59	1.92		0.31	8.68	0.35	3.07	48	402	263
10	32	702	0.68	2.61		0.37	10.29	0.41	3.67	57	475	312
11	37	703	0.78	3.28		0.43	11.90	0.45	4.27	66	546	360
12	42	704	0.89	3.84		0.47	13.51	0.46	4.86	75	612	409
13	47	704	1.00	3.89		0.52	15.12	0.46	5.44	83	675	458
14	52	703	1.12	3.89		0.57	16.73	0.46	6.00	91	737	507
15	57	703	1.26	3.89		0.61	18.33	0.46	6.54	99	737	555
16	62	703	1.42	3.89		0.65	19.94	0.46	7.05	107	858	604
17	67	703	1.61	3.89		0.68	21.55	0.46	7.50	115	917	653
18	72	702	1.84	3.89		0.72	23.16	0.46	7.87	122	975	701
19	77	702	2.13	3.89		0.76	24.77	0.46	8.13	129	1031	750
20	82	701	2.48	3.89		0.79	26.38	0.46	8.27	134	1085	799
21	87	699	2.87	3.89		0.82	27.98	0.46	8.32	140	1138	847
22	92	697	3.27	3.89		0.86	29.59	0.46	8.34	145	1190	896
23	97	695	3.63	3.89		0.95	31.20	0.46	8.34	149	1242	945
24	102	693	3.94	3.89		1.09	32.81	0.46	8.34	153	1295	994
25	112	687	4.45	3.89		1.49	36.03	0.46	8.34	153	1400	1091

* AT 15°C AND 101.325 KPA

CO_2 calculated as $(0.2805 \times N_2) - (O_2 + 0.5 \times CO)$

BASED ON PRODUCED GAS VOLUME

RUN 17 ESTEVAN LIGNITE (AIR CARBON) ~45KPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*
	0	647										
1	2	617	0.03	0.04		0.03	0.34	0.01	0.07	1	25	19
2	4	636	0.10	0.17		0.08	1.12	0.04	0.27	5	54	39
3	6	652	0.16	0.32		0.11	1.36	0.08	0.52	9	84	58
4	8	662	0.21	0.47		0.13	2.62	0.11	0.79	13	115	73
5	10	666	0.25	0.62		0.15	3.37	0.15	1.08	18	145	97
6	12	668	0.30	0.77		0.18	4.19	0.19	1.39	23	178	117
7	17	672	0.43	0.99		0.22	6.09	0.26	2.11	34	251	166
8	22	694	0.55	1.32		0.27	7.99	0.33	2.84	45	327	214
9	27	700	0.64	2.07		0.32	9.59	0.39	3.44	54	402	263
10	32	702	0.73	2.76		0.38	11.19	0.45	4.04	63	475	312
11	37	703	0.83	3.42		0.43	12.75	0.49	4.53	71	546	360
12	42	704	0.93	3.95		0.48	14.29	0.50	5.19	79	612	409
13	47	704	1.06	4.01		0.54	16.08	0.50	5.83	89	675	458
14	52	703	1.20	4.01		0.59	17.87	0.50	6.46	98	737	507
15	57	703	1.35	4.01		0.63	19.65	0.50	7.06	107	797	555
16	62	703	1.53	4.01		0.67	21.42	0.50	7.62	115	853	604
17	67	703	1.73	4.01		0.71	23.19	0.50	8.11	124	917	653
18	72	702	1.99	4.01		0.75	24.95	0.50	8.52	132	975	701
19	77	702	2.30	4.01		0.79	26.70	0.50	8.80	139	1031	750
20	82	701	2.68	4.01		0.82	28.42	0.50	8.95	145	1085	799
21	87	699	3.09	4.01		0.86	30.14	0.50	9.01	151	1138	847
22	92	697	3.52	4.01		0.91	31.86	0.50	9.02	156	1190	896
23	97	695	3.90	4.01		1.00	33.57	0.50	9.03	161	1242	945
24	102	693	4.24	4.01		1.15	35.31	0.50	9.03	165	1295	994
25	112	687	4.79	4.01		1.58	38.78	0.50	9.03	172	1400	1091

* AT 15°C AND 101.325 KPA

CO_2 calculated as $(0.2805 \times N_2)-(O_2+0.5 \times CO)$

BASED ON SUPPLIED AIR VOLUME

RUN 18 ESTEVAN LIGNITE (AIR STEAM CARBON) ~45KPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*	STEAM GRAM
	0	649											
1	5	623	0.10	0.59		0.13	1.28	0.05	0.26	5	84	39	35
2	15	630	0.29	2.99		0.38	3.83	0.17	0.91	16	233	116	110
3	20	631	0.37	4.73		0.38	5.11	0.25	1.36	24	385	155	147
4	25	629	0.48	6.06		0.44	6.33	0.31	1.75	30	488	193	184
5	30	627	0.58	7.27		0.50	7.66	0.34	2.14	37	583	232	221
6	35	624	0.65	8.52		0.57	8.93	0.36	2.56	43	686	271	258
7	40	623	0.74	10.40		0.65	10.21	0.38	2.94	49	778	309	295
8	45	622	0.86	13.17		0.71	11.49	0.38	3.29	54	861	348	332
9	50	620	1.06	14.24		0.77	12.76	0.39	3.50	59	925	387	369
10	55	619	1.28	14.48		0.94	14.37	0.39	3.61	63	977	435	406
11	60	618	1.50	14.76		1.15	15.98	0.39	3.67	67	1034	484	443
12	65	614	1.79	14.99		1.29	17.59	0.39	3.70	71	1088	533	480
13	70	612	2.08	14.99		1.45	19.20	0.39	3.71	74	1141	581	517
14	75	603	2.36	14.99		1.63	20.81	0.39	3.71	77	1194	630	555
15	80	606	2.59	14.99		1.85	22.41	0.39	3.71	80	1246	679	592
16	85	602	2.80	14.99		2.09	24.02	0.39	3.71	83	1298	727	629
17	90	619	3.01	14.99		2.32	25.63	0.39	3.71	85	1349	776	629
18	95	625	3.21	14.99		2.58	27.24	0.39	3.71	88	1402	825	629
19	100	627	3.45	14.99		2.79	28.85	0.39	3.71	90	1455	874	629
20	105	627	3.67	14.99		3.02	30.46	0.39	3.71	93	1512	922	629

* AT 15°C AND 101.325 KPA

CO_2 calculated as $(0.2805 \times N_2) - (O_2 + 0.5 \times CO)$

BASED ON PRODUCED GAS VOLUME

RUN 18 ESTEVAN LIGNITE (AIR STEAM CARBON) ~45KPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*	STEAM GRAM
	0	649											
1	5	623	0.07	0.43		0.10	0.34	0.04	0.19	4	84	39	36
2	15	630	0.34	3.75		0.37	4.46	0.21	1.09	20	233	116	110
3	20	631	0.43	5.82		0.43	5.93	0.30	1.60	28	385	155	147
4	25	629	0.58	7.56		0.51	7.69	0.38	2.14	37	488	193	184
5	30	627	0.72	9.25		0.59	9.46	0.42	2.69	46	589	232	221
6	35	624	0.81	10.90		0.69	11.15	0.45	3.24	54	686	271	258
7	40	623	0.90	12.36		0.78	12.47	0.46	3.64	60	773	309	295
8	45	622	1.00	14.99		0.82	13.46	0.47	3.91	64	861	348	332
9	50	620	1.19	16.03		0.87	14.70	0.47	4.11	69	925	387	369
10	55	619	1.39	16.25		1.04	16.18	0.47	4.22	73	977	435	406
11	60	618	1.62	16.53		1.24	17.32	0.47	4.28	76	1034	484	443
12	65	614	1.90	16.76		1.39	19.42	0.47	4.31	80	1088	533	480
13	70	612	2.22	16.76		1.56	21.17	0.47	4.31	84	1141	581	517
14	75	609	2.52	16.76		1.75	22.93	0.47	4.31	88	1194	630	555
15	80	606	2.77	16.76		1.99	24.65	0.47	4.31	91	1246	679	592
16	85	602	2.99	16.76		2.24	26.36	0.47	4.31	93	1298	727	629
17	90	619	3.22	16.76		2.49	28.04	0.47	4.31	96	1349	776	629
18	95	625	3.43	16.76		2.77	29.78	0.47	4.31	99	1402	825	629
19	100	627	3.69	16.76		3.00	31.52	0.47	4.31	102	1455	874	629
20	105	627	3.95	16.76		3.26	33.41	0.47	4.31	105	1512	922	629

* AT 15°C AND 101.325 KPA

CO_2 calculated as $(0.2805 \times N_2) - (O_2 + 0.5 \times CO)$

BASED ON SUPPLIED AIR VOLUME

RUN 19 ESTEVAN LIGNITE (AIR STEAM CARBON) ~45KPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*	STEAM GRAM
	0	941											
1	5	897		1.41		0.06	1.06	0.17	0.81	12	110	32	438
2	15	919		4.90		0.16	3.17	0.50	2.30	40	352	96	112
3	20	920		7.86		0.19	4.34	0.63	4.10	57	469	131	149
4	25	918		10.32		0.22	5.51	0.69	5.27	71	531	167	186
5	30	916		11.91		0.26	6.68	0.72	6.30	84	689	202	223
6	35	914		13.50		0.30	7.32	0.74	7.26	96	795	240	260
7	40	903		14.92		0.34	9.19	0.75	8.04	105	895	279	297
8	45	903	0.14	15.73		0.37	10.47	0.75	8.42	112	968	317	334
9	50	906	0.40	16.10		0.41	11.74	0.75	8.54	116	1036	356	371
10	55	895	0.63	16.29		0.51	13.02	0.75	8.57	119	1057	394	408
11	60	912	0.78	16.36		0.72	14.30	0.75	8.57	121	1093	433	408
12	65	915	0.89	16.36		0.97	15.57	0.75	8.57	123	1130	472	408

* AT 15°C AND 101.325 KPA

CO_2 calculated as $(0.2805 \times N_2) - (O_2 + 0.5 \times CO)$

BASED ON PRODUCED GAS VOLUME

RUN 19 ESTEVAN LIGNITE (AIR STEAM CARBON) ~45KPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*	STEAM GRAM
	0	941											
1	5	897		0.93		0.04	0.70	0.11	0.54	8	110	32	438
2	15	919		5.40		0.16	3.40	0.53	3.08	43	352	96	112
3	20	920		8.02		0.19	4.44	0.65	4.23	59	469	131	149
4	25	918		10.40		0.22	5.57	0.70	5.36	73	581	167	136
5	30	916		12.28		0.27	6.95	0.74	6.58	88	689	202	223
6	35	914		14.13		0.32	8.39	0.77	7.70	102	795	240	260
7	40	909		15.83		0.36	9.92	0.77	8.63	113	895	278	297
8	45	909	0.16	16.79		0.40	11.43	0.77	9.08	120	968	317	334
9	50	906	0.52	17.31		0.45	13.21	0.77	9.25	127	1036	356	371
10	55	895	0.64	17.40		0.50	13.81	0.77	9.26	123	1057	394	403
11	60	912	0.77	17.46		0.69	14.95	0.77	9.27	130	1093	433	408
12	65	915	0.87	17.46		0.93	16.19	0.77	9.27	131	1130	472	408

* AT 15°C AND 101.325 KPA

CO_2 calculated as $(0.2805 \times N_2) - (O_2 + 0.5 \times CO)$

BASED ON SUPPLIED AIR VOLUME

RUN 20 ESTEVAN LIGNITE (AIR CARBON) ~45KPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*
	0	912										
1	10	927		1.41		0.16	2.48	0.20	1.05	15	199	75
2	15	939	0.02	2.07		0.24	3.75	0.29	1.60	23	273	114
3	20	942	0.04	3.45		0.29	5.03	0.36	2.17	31	338	152
4	25	939	0.06	4.49		0.32	6.31	0.38	2.78	38	397	191
5	30	939	0.09	4.59		0.37	7.58	0.38	3.35	46	449	230
6	35	940	0.12	4.59		0.42	8.86	0.38	3.90	53	499	268
7	40	943	0.15	4.59		0.46	10.14	0.38	4.48	60	549	307
8	45	942	0.18	4.59		0.51	11.41	0.38	5.04	67	599	346
9	55	936	0.23	4.59		0.63	13.97	0.38	6.12	81	699	423
10	60	938	0.25	4.59		0.69	15.24	0.38	6.66	87	749	462
11	65	927	0.30	4.59		0.74	16.52	0.38	7.18	94	797	500
12	70	925	0.43	4.59		0.78	17.79	0.38	7.56	101	844	539
13	75	920	0.63	4.59		0.82	19.07	0.38	7.80	106	888	578
14	80	915	0.85	4.59		0.86	20.35	0.38	7.99	111	931	616
15	85	916	1.11	4.59		0.90	21.62	0.38	8.12	115	972	655
16	90	913	1.39	4.59		0.94	22.90	0.38	8.19	120	1013	693
17	95	913	1.67	4.59		1.00	24.18	0.38	8.22	123	1052	732
18	100	910	1.98	4.59		1.05	25.45	0.38	8.22	127	1090	771
19	105	917	2.31	4.59		1.08	26.73	0.38	8.22	131	1132	809
20	110	910	2.63	4.59		1.11	28.01	0.38	8.23	135	1169	848
21	115	911	2.93	4.59		1.17	29.28	0.38	8.23	139	1208	887
22	120	912	3.20	4.59		1.25	30.56	0.38	8.23	142	1248	925

* AT 15°C AND 101.325 KPA

CO_2 calculated as $(0.2805 \times N_2) - (O_2 + 0.5 \times CO)$

BASED ON PRODUCED GAS VOLUME

RUN 20 ESTEVAN LIGNITE (AIR CARBON) ~45KPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*
	0	912										
1	10	927		1.12		0.13	1.96	0.16	0.83	12	193	75
2	15	939	0.02	1.89		0.21	3.46	0.27	1.47	21	273	114
3	20	942	0.04	3.02		0.25	4.51	0.33	1.94	28	338	152
4	25	939	0.05	3.89		0.28	5.57	0.34	2.45	34	397	191
5	30	939	0.08	4.00		0.33	6.95	0.34	3.07	42	449	230
6	35	940	0.12	4.00		0.39	8.37	0.34	3.68	50	499	268
7	40	943	0.15	4.00		0.43	9.77	0.34	4.31	58	549	307
8	45	942	0.18	4.00		0.49	11.18	0.34	4.93	65	599	346
9	55	936	0.24	4.00		0.63	14.02	0.34	6.14	81	699	423
10	60	938	0.26	4.00		0.70	15.43	0.34	6.73	88	749	462
11	65	927	0.32	4.00		0.75	16.81	0.34	7.23	95	797	500
12	70	925	0.46	4.00		0.79	18.18	0.34	7.70	102	844	539
13	75	920	0.68	4.00		0.83	19.56	0.34	7.96	108	888	578
14	80	915	0.90	4.00		0.87	20.88	0.34	8.16	113	931	616
15	85	916	1.17	4.00		0.91	22.19	0.34	8.29	118	972	655
16	90	913	1.46	4.00		0.95	23.51	0.34	8.37	122	1013	693
17	95	913	1.74	4.00		1.02	24.78	0.34	8.39	126	1052	732
18	100	910	2.04	4.00		1.07	26.05	0.34	8.40	129	1090	771
19	105	917	2.41	4.00		1.09	27.45	0.34	8.40	134	1132	809
20	110	910	2.71	4.00		1.13	28.67	0.34	8.40	137	1169	848
21	115	911	3.02	4.00		1.18	29.95	0.34	8.40	141	1208	887
22	120	912	3.29	4.00		1.27	31.25	0.34	8.40	144	1248	925

* AT 15°C AND 101.325 KPA

CO_2 calculated as $(0.2805 \times N_2)-(O_2+0.5 \times CO)$

BASED ON SUPPLIED AIR VOLUME

RUN 21A ESTEVAN LIGNITE (AIR STEAM CARBON) 2MPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*	STEAM GRAM
	0	671											
1	5	943	0.07	0.32		0.01	1.16	0.12	0.48	8	89	35	25
2	10	965	0.11	0.76		0.03	2.32	0.27	1.03	17	189	70	45
3	15	975	0.14	1.65		0.04	3.48	0.41	1.58	26	296	105	69
4	20	1020	0.23	2.47		0.06	4.64	0.47	2.02	33	379	140	93
5	25	936	0.28	2.76		0.07	5.24	0.51	2.24	36	442	159	118
6	30	923	0.33	3.10		0.08	5.83	0.54	2.46	40	473	177	142
7	35	914	0.38	3.45		0.09	6.43	0.56	2.69	44	516	195	168
8	40	908	0.43	3.75		0.09	7.03	0.58	2.90	47	558	213	194
9	45	904	0.48	4.01		0.11	7.63	0.61	3.11	50	602	231	222
10	50	906	0.53	4.23		0.12	8.23	0.64	3.33	54	646	249	245
11	55	909	0.58	4.59		0.13	8.83	0.67	3.55	58	691	267	271
12	60	914	0.63	4.99		0.13	9.43	0.70	3.76	61	738	285	298
13	65	918	0.68	5.40		0.14	10.02	0.73	3.99	65	783	304	323
14	70	921	0.72	5.75		0.15	10.62	0.77	4.21	68	827	322	350
15	75	939	0.77	6.11		0.16	11.22	0.79	4.43	72	870	340	376
16	80	943	0.82	6.46		0.17	11.82	0.82	4.66	76	910	358	402
17	85	947	0.87	6.79		0.18	12.42	0.85	4.88	79	945	376	430
18	90	940	0.92	7.10		0.19	13.02	0.87	5.09	83	978	394	3965
19	95	928	0.98	7.38		0.19	13.61	0.88	5.29	86	1001	412	483
20	100	820	1.06	7.61		0.20	14.21	0.89	5.46	89	1022	430	510
21	105	668	1.16	7.73		0.22	14.81	0.90	5.54	91	1044	449	537
22	110	568	1.29	7.79		0.25	15.41	0.90	5.57	93	1096	467	550

* AT 15°C AND 101.325 KPA

CO_2 calculated as $(0.2805 \times N_2) - (O_2 + 0.5 \times CO)$

BASED ON PRODUCED GAS VOLUME

RUN 21A ESTEVAN LIGNITE · (AIR STEAM CARBON) 2MPA

SAMPLE NO.	TIME MIN.	TEMP. •C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*	STEAM GRAM
	0	671											
1	5	943	0.06	0.28		0.01	1.00	0.10	0.42	7	89	35	25
2	10	965	0.13	1.07		0.04	3.10	0.38	1.40	23	139	70	45
3	15	975	0.18	2.51		0.06	4.98	0.60	2.31	37	296	105	69
4	20	1020	0.31	3.63		0.08	6.55	0.69	2.90	47	379	140	93
5	25	936	0.42	4.27		0.10	7.89	0.76	3.38	55	442	159	118
6	30	923	0.48	4.69		0.11	8.61	0.80	3.65	59	478	177	142
7	35	914	0.54	5:13		0.12	9.38	0.83	3.94	64	516	195	168
8	40	908	0.61	5.58		0.14	10.28	0.86	4.26	69	553	213	194
9	45	904	0.69	6.00		0.16	11.23	0.90	4.60	74	602	231	222
10	50	906	0.77	6.43		0.17	12.17	0.95	4.94	80	646	249	245
11	55	909	0.85	6.91		0.19	13.13	1.00	5.29	86	691	267	271
12	60	914	0.93	7.51		0.20	14.02	1.05	5.61	91	738	285	298
13	65	918	1.00	8.10		0.22	14.88	1.09	5.93	96	783	304	323
14	70	921	1.07	8.63		0.23	15.78	1.14	6.27	102	827	322	350
15	75	939	1.13	9.14		0.24	16.63	1.18	6.58	107	870	340	376
16	80	948	1.20	9.61		0.25	17.44	1.22	6.89	112	910	358	402
17	85	947	1.26	10.01		0.26	18.16	1.25	7.15	116	945	376	430
18	90	940	1.32	10.37		0.27	18.86	1.27	7.40	120	978	394	3365
19	95	928	1.37	10.60		0.28	19.35	1.28	7.57	123	1001	412	483
20	100	820	1.43	10.79		0.28	19.84	1.29	7.71	125	1022	430	510
21	105	668	1.54	10.91		0.30	20.43	1.30	7.79	127	1044	449	537
22	110	568	1.86	11.06		0.39	22.01	1.30	7.85	132	1096	467	550

* AT 15•C AND 101.325 KPA

CO_2 calculated as $(0.2805 \times N_2)-(O_2+0.5 \times CO)$

BASED ON SUPPLIED AIR VOLUME

RUN 21 ESTEVAN LIGNITE (CARBON AIR STEAM) 2MPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*	STEAM GRAM
	0	671											
1	5	943	0.22	0.95	0.01	0.10	1.16	0.08	0.33	8	89	35	25
2	10	965	0.48	1.70	0.03	0.19	2.32	0.17	0.74	17	189	70	45
3	15	975	0.76	2.33	0.05	0.29	3.48	0.31	1.21	29	296	105	69
4	20	1020	1.01	2.98	0.07	0.37	4.64	0.47	1.70	40	379	140	93
5	25	963	1.12	3.27	0.07	0.39	5.24	0.54	1.97	45	442	159	118
6	30	923	1.21	3.51	0.07	0.41	5.83	0.59	2.24	50	478	177	142
7	35	914	1.31	3.72	0.08	0.42	6.43	0.64	2.48	55	516	195	158
8	40	908	1.43	3.95	0.08	0.44	7.03	0.67	2.71	60	558	213	194
9	45	904	1.56	4.22	0.08	0.45	7.63	0.70	2.93	64	602	231	222
10	50	906	1.70	4.52	0.08	0.46	8.23	0.74	3.15	69	646	249	245
11	55	909	1.84	4.83	0.08	0.48	8.83	0.77	3.36	73	691	267	271
12	60	914	2.00	5.28	0.08	0.49	9.43	0.80	3.56	78	738	285	298
13	65	918	2.14	5.76	0.08	0.53	10.02	0.82	3.74	82	783	304	323
14	70	921	2.27	6.09	0.08	0.59	10.62	0.84	3.88	86	827	322	350
15	75	939	2.40	6.37	0.08	0.65	11.22	0.86	4.03	89	870	340	376
16	80	948	2.55	6.66	0.08	0.70	11.82	0.88	4.19	93	910	358	402
17	85	947	2.70	7.00	0.08	0.73	12.42	0.90	4.37	97	945	376	430
18	90	940	2.84	7.36	0.08	0.76	13.02	0.91	4.56	102	978	394	456
19	95	928	2.97	7.71	0.08	0.77	13.61	0.93	4.75	106	1001	412	483
20	100	820	3.10	8.00	0.08	0.78	14.21	0.94	4.93	110	1022	430	510
21	105	668	3.24	8.26	0.08	0.79	14.81	0.95	5.06	113	1044	449	537
22	110	568	3.38	8.43	0.08	0.81	15.41	0.96	5.15	116	1096	467	550

* AT 15°C AND 101.325 KPA

BASED ON PRODUCED GAS VOLUME

RUN 21 ESTEVAN LIGNITE (CARBON AIR STEAM) 2MPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*	STEAM GRAM
	0	671											
1	5	943	0.15	0.62	0.01	0.07	0.76	0.05	0.22	5	89	35	25
2	10	965	0.54	1.78	0.03	0.21	2.53	0.19	0.84	20	189	70	45
3	15	975	1.00	2.79	0.07	0.37	4.40	0.41	1.60	38	296	105	69
4	20	1020	1.31	3.60	0.09	0.47	5.86	0.62	2.21	52	379	140	93
5	25	963	1.52	4.17	0.10	0.51	7.04	0.75	2.74	63	442	158	118
6	30	923	1.62	4.46	0.10	0.53	7.75	0.82	3.06	68	478	177	142
7	35	914	1.75	4.74	0.10	0.55	8.53	0.88	3.39	75	516	195	168
8	40	908	1.93	5.08	0.10	0.57	9.41	0.93	3.72	81	558	213	194
9	45	904	2.12	5.47	0.10	0.58	10.28	0.98	4.04	88	602	231	222
10	50	906	2.32	5.89	0.10	0.60	11.15	1.02	4.35	95	646	249	245
11	55	909	2.54	6.36	0.10	0.63	12.02	1.07	4.66	102	691	267	271
12	60	914	2.74	6.96	0.10	0.64	12.83	1.11	4.93	108	738	285	298
13	65	918	2.93	7.58	0.10	0.69	13.61	1.14	5.17	113	783	304	323
14	70	921	3.12	8.07	0.11	0.78	14.49	1.17	5.38	118	827	322	350
15	75	939	3.31	8.48	0.11	0.87	15.36	1.19	5.59	124	870	340	376
16	80	948	3.51	8.87	0.11	0.94	16.16	1.22	5.80	129	910	358	402
17	85	947	3.68	9.26	0.11	0.98	16.84	1.24	6.01	134	945	376	430
18	90	940	3.83	9.63	0.11	1.00	17.46	1.26	6.20	138	978	394	456
19	95	928	3.93	9.88	0.11	1.01	17.90	1.27	6.35	141	1001	412	483
20	100	820	4.02	10.10	0.11	1.02	18.34	1.28	6.48	144	1022	430	510
21	105	668	4.13	10.30	0.11	1.03	18.82	1.29	6.58	147	1044	449	537
22	110	568	4.42	10.68	0.11	1.07	20.12	1.31	6.77	153	1096	467	550

* AT 15°C AND 101.325 KPA

BASED ON SUPPLIED AIR VOLUME

RUN 22 ESTEVAN LIGNITE (CARBON AIR STEAM) 2MPA

SAMPLE NO.	TIME MIN.	TEMP. •C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*	STEAM GRAM
	0	680											
1	5	557	0.24	0.17		0.16	0.68	0.03	0.04	4	61	21	30
2	10	840	0.54	0.49	0.01	0.27	1.36	0.09	0.12	9	122	41	58
3	15	845	0.90	1.09	0.03	0.31	2.03	0.22	0.30	18	188	62	86
4	20	860	1.23	1.76	0.04	0.34	2.71	0.42	0.53	27	254	82	113
5	25	875	1.50	2.30	0.05	0.37	3.39	0.61	0.79	36	304	103	141
6	30	889	1.73	2.71	0.05	0.40	4.07	0.72	1.04	43	344	123	169
7	35	899	1.95	3.08	0.05	0.41	4.75	0.80	1.27	49	393	144	197
8	40	910	2.18	3.43	0.05	0.42	5.42	0.86	1.50	56	443	164	224
9	45	922	2.40	3.76	0.05	0.44	6.10	0.91	1.74	62	488	185	253
10	50	934	2.57	4.09	0.05	0.48	6.78	0.95	1.93	67	532	205	280
11	55	942	2.73	4.41	0.05	0.52	7.46	0.98	2.13	71	576	226	308
12	60	954	2.90	4.69	0.05	0.54	8.14	1.02	2.37	77	614	246	336
13	65	942	3.06	4.93	0.05	0.56	8.81	1.05	2.62	82	657	267	364
14	70	945	3.21	5.19	0.05	0.57	9.43	1.08	2.88	87	697	287	392
15	75	947	3.36	5.45	0.05	0.58	10.17	1.10	3.13	92	737	308	420
16	80	949	3.52	5.69	0.05	0.59	10.85	1.12	3.39	98	776	328	449
17	85	948	3.67	5.92	0.05	0.60	11.52	1.14	3.64	103	814	349	476
18	90	946	3.83	6.14	0.05	0.61	12.20	1.16	3.89	108	849	370	504
19	95	939	3.97	6.36	0.05	0.62	12.88	1.17	4.12	112	883	390	532
20	100	934	4.11	6.55	0.05	0.63	13.56	1.18	4.33	117	916	411	560
21	105	926	4.26	6.70	0.05	0.64	14.24	1.19	4.52	121	945	431	588
22	110	902	4.42	6.83	0.05	0.65	14.91	1.20	4.67	125	967	452	617
23	115	612	4.57	6.91	0.05	0.66	15.59	1.20	4.77	128	989	472	645
24	120	652	4.68	6.95	0.05	0.73	16.27	1.21	4.81	130	1009	493	674

* AT 15•C AND 101.325 KPA

BASED ON SUPPLIED AIR VOLUME

RUN 22 ESTEVAN LIGNITE (CARBON AIR STEAM) 2MPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*	STEAM GRAM
	0	660											
1	5	557	0.24	0.17		0.16	0.68	0.03	0.04	4	61	21	30
2	10	840	0.54	0.49	0.01	0.27	1.36	0.09	0.12	9	122	41	58
3	15	845	0.90	1.09	0.03	0.31	2.03	0.22	0.30	18	188	62	86
4	20	860	1.23	1.76	0.04	0.34	2.71	0.42	0.53	27	254	82	113
5	25	875	1.50	2.30	0.05	0.37	3.39	0.61	0.79	36	304	103	141
6	30	889	1.73	2.71	0.05	0.40	4.07	0.72	1.04	43	344	123	169
7	35	899	1.95	3.08	0.05	0.41	4.75	0.80	1.27	49	393	144	197
8	40	910	2.18	3.43	0.05	0.42	5.42	0.86	1.50	56	443	164	224
9	45	922	2.40	3.76	0.05	0.44	6.10	0.91	1.74	62	488	185	253
10	50	934	2.57	4.09	0.05	0.48	6.78	0.95	1.93	67	532	205	280
11	55	942	2.73	4.41	0.05	0.52	7.46	0.98	2.13	71	576	226	308
12	60	954	2.90	4.69	0.05	0.54	8.14	1.02	2.37	77	614	246	336
13	65	942	3.06	4.93	0.05	0.56	8.81	1.05	2.62	82	657	267	364
14	70	945	3.21	5.19	0.05	0.57	9.49	1.08	2.88	87	697	287	392
15	75	947	3.36	5.45	0.05	0.58	10.17	1.10	3.13	92	737	308	420
16	80	949	3.52	5.69	0.05	0.59	10.85	1.12	3.39	98	776	328	449
17	85	948	3.67	5.92	0.05	0.60	11.52	1.14	3.64	103	814	349	476
18	90	946	3.83	6.14	0.05	0.61	12.20	1.16	3.89	108	849	370	504
19	95	939	3.97	6.36	0.05	0.62	12.88	1.17	4.12	112	883	390	532
20	100	934	4.11	6.55	0.05	0.63	13.56	1.18	4.33	117	916	411	560
21	105	926	4.26	6.70	0.05	0.64	14.24	1.19	4.52	121	945	431	588
22	110	902	4.42	6.83	0.05	0.65	14.91	1.20	4.67	125	967	452	617
23	115	612	4.57	6.91	0.05	0.66	15.59	1.20	4.77	128	989	472	645
24	120	652	4.68	6.95	0.05	0.73	16.27	1.21	4.81	130	1009	493	674

* AT 15°C AND 101.325 KPA

BASED ON SUPPLIED AIR VOLUME

RUN23 ESTEVAN LIGNITE (CARBON AIR STEAM) 2MPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*	STEAM GRAM
	0	662											
1	5	383	0.09	0.12			0.23	0.02	0.08	2	9	7	28
2	10	668	0.12	0.17		0.04	0.47	0.02	0.11	3	18	14	56
3	15	751	0.13	0.26		0.10	0.70	0.03	0.12	3	25	21	85
4	20	753	0.22	0.48	0.01	0.15	0.94	0.04	0.14	5	31	28	114
5	25	763	0.39	0.69	0.01	0.19	1.17	0.09	0.16	8	39	36	143
6	30	772	0.53	0.87	0.02	0.23	1.41	0.14	0.19	11	41	43	171
7	35	786	0.68	1.05	0.03	0.25	1.64	0.20	0.21	14	44	50	200
8	40	793	0.89	1.36	0.04	0.26	1.88	0.34	0.26	19	46	57	229
9	45	811	1.07	1.62	0.05	0.27	2.11	0.47	0.30	23	48	64	257
10	50	824	1.24	1.85	0.06	0.28	2.35	0.57	0.33	27	50	71	286
11	55	844	1.37	2.06	0.07	0.31	2.58	0.65	0.37	30	51	78	314
12	60	863	1.50	2.28	0.07	0.33	2.82	0.74	0.41	34	51	85	344
13	65	906	2.08	3.38	0.10	0.34	3.66	1.14	0.62	43	66	111	372
14	70	861	2.59	4.29	0.11	0.36	4.51	1.40	0.83	61	93	137	400
15	75	831	3.07	5.09	0.11	0.37	5.36	1.58	1.08	71	115	162	429
16	80	810	3.50	5.34	0.12	0.38	6.20	1.70	1.37	82	141	188	458
17	85	798	3.89	6.52	0.12	0.39	7.05	1.81	1.69	92	161	213	488
18	90	785	4.25	7.17	0.12	0.40	7.89	1.90	2.01	101	184	239	525
19	95	772	4.56	7.79	0.12	0.41	8.74	1.93	2.32	109	198	265	543
20	100	760	4.86	8.40	0.12	0.42	9.59	2.07	2.64	118	215	290	572
21	105	751	5.17	8.93	0.13	0.43	10.43	2.14	2.95	126	234	316	601
22	110	741	5.48	9.43	0.13	0.44	11.28	2.20	3.26	134	246	342	630
23	115	732	5.78	9.99	0.13	0.45	12.13	2.26	3.55	142	263	367	658
24	120	725	6.07	10.47	0.13	0.47	12.97	2.31	3.85	150	281	393	688
25	125	720	6.36	10.95	0.13	0.48	13.82	2.35	4.14	157	296	418	715
26	135	709	6.92	11.89	0.14	0.50	15.51	2.43	4.73	172	328	470	775
27	145	694	7.47	12.78	0.14	0.52	17.20	2.51	5.31	187	343	521	831
28	155	683	8.00	13.58	0.14	0.54	18.90	2.56	5.81	200	359	572	889
29	165	672	8.47	14.14	0.14	0.56	20.59	2.60	6.13	210	383	623	943
30	175	662	8.84	14.37	0.14	0.65	22.28	2.61	6.24	216	420	675	1005
31	190	661	9.18	14.48	0.15	1.01	24.82	2.63	6.23	221	483	752	1090
32	200	659	9.30	14.53	0.15	1.38	26.51	2.63	6.30	222	524	803	1148

* AT 15°C AND 101.325 KPA

BASED ON PRODUCED GAS VOLUME

RUN23 ESTEVAN LIGNITE (CARBON AIR STEAM) 2MPA

SAMPLE NO.	TIME MIN.	TEMP. •C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*	STEAM GRAM
	0	662											
1	5	383	0.03	0.04			0.09	0.01	0.03	1	9	7	28
2	10	668	0.06	0.09		0.04	0.31	0.01	0.06	2	18	14	56
3	15	751	0.07	0.15		0.07	0.47	0.01	0.06	2	25	21	85
4	20	753	0.11	0.24		0.10	0.56	0.02	0.07	3	31	28	114
5	25	763	0.18	0.33	0.01	0.12	0.67	0.04	0.08	4	39	36	143
6	30	772	0.20	0.36	0.01	0.12	0.70	0.05	0.09	4	41	43	171
7	35	786	0.23	0.40	0.01	0.13	0.75	0.06	0.09	5	44	50	200
8	40	798	0.25	0.42	0.01	0.13	0.77	0.07	0.10	5	46	57	229
9	45	811	0.26	0.44	0.01	0.13	0.79	0.08	0.10	6	48	64	257
10	50	824	0.29	0.47	0.01	0.13	0.82	0.10	0.10	6	50	71	286
11	55	844	0.29	0.48	0.01	0.13	0.83	0.10	0.10	6	51	78	314
12	60	863	0.29	0.48	0.01	0.13	0.83	0.10	0.10	6	51	85	344
13	65	906	0.41	0.70	0.02	0.13	1.00	0.18	0.15	9	66	111	372
14	70	861	0.58	1.01	0.02	0.14	1.28	0.27	0.22	13	88	137	400
15	75	831	0.79	1.37	0.02	0.14	1.66	0.35	0.33	18	115	162	428
16	80	810	0.99	1.70	0.02	0.15	2.04	0.40	0.46	23	141	188	458
17	85	793	1.13	1.95	0.03	0.15	2.35	0.44	0.57	26	161	213	488
18	90	786	1.28	2.23	0.03	0.16	2.71	0.48	0.71	30	184	239	525
19	95	772	1.36	2.39	0.03	0.16	2.93	0.50	0.79	33	198	265	543
20	100	760	1.46	2.59	0.03	0.16	3.22	0.53	0.90	35	215	290	572
21	105	751	1.58	2.82	0.03	0.17	3.54	0.56	1.02	39	234	316	601
22	110	741	1.66	2.94	0.03	0.17	3.75	0.57	1.10	41	246	342	630
23	115	732	1.77	3.12	0.03	0.17	4.06	0.59	1.20	43	263	367	658
24	120	725	1.97	3.30	0.03	0.18	4.37	0.61	1.31	46	281	393	688
25	125	720	1.97	3.46	0.03	0.18	4.66	0.63	1.41	49	296	418	715
26	135	703	2.17	3.79	0.03	0.19	5.24	0.65	1.62	54	328	470	775
27	145	694	2.26	3.93	0.03	0.19	5.52	0.67	1.71	56	343	521	831
28	155	683	2.36	4.09	0.03	0.20	5.84	0.68	1.80	58	359	572	889
29	165	672	2.51	4.27	0.03	0.20	6.39	0.69	1.91	62	383	623	948
30	175	662	2.74	4.41	0.03	0.26	7.44	0.70	1.98	66	420	675	1005
31	190	661	3.01	4.49	0.03	0.54	9.44	0.71	2.01	70	483	752	1090
32	200	659	3.10	4.54	0.03	0.82	10.71	0.71	2.03	71	524	803	1148

* AT 15•C AND 101.325 KPA

BASED ON SUPPLIED AIR VOLUME

RUN 24 ESTEVAN LIGNITE (CARBON AIR STEAM) 4MPA

SAMPLE NO.	TIME MIN.	TEMP. •C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*	STEAM GRAM
	0	656											
1	5	1023	0.90	1.21	0.03	0.12	2.54	0.25	0.86	25	136	77	63
2	10	1026	1.77	2.87	0.05	0.22	5.09	0.56	1.36	51	295	154	125
3	15	997	2.57	4.90	0.08	0.30	7.63	1.02	3.03	92	434	231	188
4	20	1008	3.24	6.40	0.10	0.37	10.17	1.41	4.20	109	564	308	253
5	25	1035	3.71	7.36	0.11	0.44	12.72	1.61	5.32	130	686	385	315
6	30	1059	4.07	8.03	0.11	0.51	15.26	1.72	6.43	149	798	462	378
7	35	985	4.40	8.58	0.11	0.56	17.80	1.78	7.56	158	898	539	441
8	40	895	4.68	8.95	0.11	0.59	20.35	1.81	8.63	184	983	616	504
9	45	872	5.03	9.10	0.11	0.65	22.94	1.82	9.30	196	1072	695	566
10	50	804	5.39	9.12	0.11	0.85	25.48	1.82	9.51	203	1166	772	629
11	55	734	5.60	9.12	0.11	1.29	28.02	1.82	9.55	206	1258	849	693
12	60	709	5.71	9.12	0.11	1.84	30.57	1.82	9.57	208	1349	926	755
13	65	690	5.79	9.12	0.11	2.44	33.11	1.82	9.58	209	1439	1003	819
14	70	677	5.83	9.12	0.11	3.05	35.65	1.82	9.59	210	1530	1080	882
15	75	671	5.86	9.12	0.11	3.68	38.20	1.82	9.59	210	1575	1157	944

* AT 15•C AND 101.325 KPA

BASED ON PRODUCED GAS VOLUME

RUN 24 ESTEVAN LIGNITE (CARBON AIR STEAM) 4MPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*	STEAM GRAM
	0	656											
1	5	1023	0.44	0.59	0.01	0.06	1.24	0.12	0.42	12	136	77	63
2	10	1026	1.34	2.30	0.04	0.16	3.87	0.44	1.44	40	295	154	125
3	15	997	2.00	3.98	0.07	0.23	5.97	0.82	2.42	64	434	231	188
4	20	1008	2.58	5.27	0.08	0.29	8.17	1.16	3.43	88	564	308	253
5	25	1035	3.03	6.20	0.09	0.35	10.61	1.35	4.50	109	686	385	315
6	30	1059	3.38	6.85	0.09	0.42	13.08	1.46	5.58	127	798	462	378
7	35	985	3.68	7.35	0.09	0.46	15.39	1.51	6.60	144	898	539	441
8	40	895	3.91	7.66	0.09	0.49	17.50	1.53	7.50	158	983	616	504
9	45	872	4.26	7.80	0.09	0.55	20.05	1.54	8.16	170	1072	695	566
10	50	804	4.68	7.83	0.09	0.79	23.08	1.55	8.40	178	1166	772	629
11	55	734	4.94	7.83	0.09	1.32	26.14	1.55	8.45	181	1258	849	693
12	60	709	5.07	7.83	0.09	1.98	29.18	1.55	8.47	183	1349	926	755
13	65	690	5.16	7.83	0.09	2.68	32.19	1.55	8.49	184	1439	1003	819
14	70	677	5.21	7.83	0.09	3.42	35.21	1.55	8.50	185	1530	1080	882
15	75	571	5.23	7.83	0.09	3.79	36.74	1.55	8.50	185	1575	1157	944

* AT 15°C AND 101.325 KPA

BASED ON SUPPLIED AIR VOLUME

RUN 25 ESTEVAN LIGNITE (CARBON AIR STEAM) 4MPA

SAMPLE NO.	TIME MIN.	TEMP. •C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*	STEAM GRAM
	0	656											
1	5	820	0.08			0.28	1.15			1	30	35	70
2	10	883	0.46	0.27	0.01	0.51	2.38	0.08	0.07	8	151	72	134
3	15	904	1.33	1.15	0.04	0.58	3.62	0.38	0.41	26	221	110	137
4	20	965	2.00	2.04	0.07	0.61	4.85	0.77	0.87	45	269	147	261
5	25	1000	2.57	2.91	0.09	0.63	6.09	1.19	1.36	64	312	184	323
6	30	1026	3.02	3.55	0.10	0.65	7.32	1.48	1.80	78	346	222	386
7	35	1017	3.40	4.04	0.11	0.67	8.56	1.67	2.19	90	383	259	450
8	40	1004	3.73	4.40	0.11	0.69	9.79	1.81	2.56	100	421	296	512
9	45	971	3.98	4.63	0.11	0.71	11.02	1.89	2.92	108	464	334	574
10	50	946	4.19	4.78	0.11	0.73	12.26	1.93	3.28	115	511	371	638
11	55	935	4.37	4.90	0.11	0.75	13.49	1.96	3.65	122	562	409	701
12	60	929	4.56	5.03	0.11	0.77	14.73	1.98	4.04	130	611	446	764
13	65	931	4.76	5.21	0.11	0.79	15.96	2.01	4.43	137	660	483	828
14	70	934	4.99	5.43	0.11	0.81	17.20	2.05	4.83	145	706	521	893
15	75	922	5.22	5.67	0.11	0.83	18.43	2.08	5.23	153	751	558	954
16	80	900	5.44	5.90	0.11	0.86	19.66	2.10	5.61	161	795	595	1016
17	85	872	5.67	6.10	0.11	0.88	20.90	2.12	5.97	168	838	633	1082
18	90	771	5.91	6.27	0.11	0.90	22.13	2.14	6.27	174	881	670	1143
19	95	698	6.16	6.42	0.11	0.92	23.37	2.15	6.51	181	918	708	1206
20	100	684	6.44	6.55	0.11	0.94	24.60	2.16	6.65	186	958	745	1269
21	105	671	6.67	6.63	0.11	1.02	25.84	2.16	6.72	189	995	782	1333
22	110	658	6.81	6.65	0.11	1.19	27.07	2.16	6.75	191	1033	820	1395
23	115	647	6.90	6.65	0.11	1.43	28.30	2.16	6.76	193	1069	857	1449
24	120	643	6.95	6.65	0.11	1.71	29.54	2.16	6.77	193	1102	895	1449

* AT 15•C AND 101.325 KPA

BASED ON PRODUCED GAS VOLUME

RUN 25 ESTEVAN LIGNITE (CARBON AIR STEAM) 4MPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO_2	H_2	C_2	O_2	N_2	CH_4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*	STEAM GRAM
	0	656											
1	5	820	0.09			0.31	1.29			1	80	35	70
2	10	883	0.59	0.36	0.01	0.62	2.92	0.11	0.10	10	151	72	134
3	15	904	1.28	1.05	0.04	0.67	3.90	0.34	0.36	25	221	110	197
4	20	965	1.64	1.54	0.05	0.69	4.57	0.56	0.61	35	269	147	261
5	25	1000	1.93	1.97	0.07	0.70	5.19	0.77	0.86	44	312	184	323
6	30	1026	2.14	2.28	0.07	0.71	5.77	0.90	1.07	51	346	222	386
7	35	1017	2.36	2.56	0.07	0.72	6.49	1.02	1.29	58	383	259	450
8	40	1004	2.57	2.80	0.07	0.74	7.29	1.10	1.54	64	421	296	512
9	45	971	2.78	2.99	0.08	0.76	8.32	1.17	1.83	71	464	334	574
10	50	948	2.99	3.14	0.08	0.78	9.55	1.21	2.19	79	511	371	638
11	55	935	3.19	3.26	0.08	0.80	10.91	1.24	2.60	86	562	409	701
12	60	929	3.39	3.40	0.08	0.82	12.21	1.27	3.01	94	611	446	764
13	65	931	3.59	3.58	0.08	0.84	13.43	1.30	3.40	101	660	483	828
14	70	934	3.80	3.78	0.08	0.85	14.55	1.33	3.76	108	706	521	893
15	75	922	4.00	3.99	0.08	0.87	15.64	1.36	4.11	115	751	558	954
16	80	900	4.20	4.19	0.08	0.89	16.74	1.38	4.45	122	795	595	1016
17	85	872	4.40	4.37	0.08	0.91	17.81	1.40	4.76	128	838	633	1082
18	90	771	4.62	4.53	0.08	0.93	18.97	1.41	5.05	135	881	670	1143
19	95	698	4.83	4.65	0.08	0.95	19.98	1.42	5.24	140	918	708	1206
20	100	684	5.08	4.77	0.08	0.97	21.11	1.43	5.37	144	958	745	1269
21	105	671	5.29	4.85	0.08	1.04	22.26	1.43	5.43	148	995	782	1333
22	110	658	5.44	4.86	0.08	1.21	23.50	1.43	5.46	150	1033	820	1395
23	115	647	5.53	4.86	0.08	1.45	24.71	1.43	5.48	151	1069	857	1449
24	120	643	5.57	4.86	0.08	1.69	25.79	1.43	5.49	152	1102	895	1449

* AT 15°C AND 101.325 KPA

BASED ON SUPPLIED AIR VOLUME

RUN 26 ESTEVAN LIGNITE (CARBON AIR STEAM) 2MPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*	STEAM GRAM
	0	855											
1	5	771	0.79	1.17	0.02	0.03	1.16	0.19	0.36	17	83	35	58
2	10	814	1.59	2.72	0.05	0.05	2.32	0.44	0.81	35	181	70	125
3	15	813	2.40	4.51	0.07	0.07	3.48	0.82	1.37	57	283	105	193
4	20	857	3.15	6.00	0.09	0.08	4.64	1.22	1.90	77	360	140	260
5	25	864	3.79	7.24	0.10	0.10	5.80	1.46	2.33	93	432	176	323
6	30	865	4.33	8.24	0.10	0.11	6.96	1.58	2.69	106	499	211	397
7	35	863	4.80	9.10	0.10	0.13	8.12	1.68	3.06	117	559	246	464
8	40	855	5.20	9.77	0.11	0.14	9.28	1.76	3.43	127	617	281	532
9	45	844	5.56	10.27	0.11	0.16	10.44	1.83	3.32	137	674	316	600
10	50	830	5.88	10.72	0.11	0.17	11.59	1.88	4.20	146	731	351	667
11	55	810	6.19	11.13	0.11	0.19	12.75	1.92	4.53	155	789	386	735
12	60	796	6.50	11.64	0.11	0.20	13.91	1.96	4.96	164	847	421	802
13	65	786	6.83	12.16	0.11	0.22	15.07	2.00	5.32	172	900	456	871
14	70	778	7.15	12.54	0.11	0.23	16.23	2.02	5.63	180	947	492	938
15	75	753	7.46	12.83	0.11	0.25	17.39	2.04	5.85	187	991	527	1006
16	80	765	7.76	13.02	0.11	0.26	18.55	2.05	6.00	192	1023	562	1073
17	85	746	8.06	13.12	0.11	0.28	19.71	2.06	6:07	197	1094	597	1142
18	90	685	8.31	13.16	0.11	0.34	20.87	2.06	5.09	200	1106	632	1210
19	95	671	8.51	13.17	0.11	0.46	22.03	2.06	6.10	203	1147	667	1278
20	100	662	8.62	13.17	0.11	0.66	23.19	2.06	6.11	204	1187	702	1344
21	105	654	8.68	13.17	0.11	0.92	24.35	2.06	6.12	205	1228	737	1412

* AT 15°C AND 101.325 KPA

BASED ON PRODUCED GAS VOLUME

RUN 26 ESTEVAN LIGNITE (CARBON AIR STEAM) 2MPA

SAMPLE NO.	TIME MIN.	TEMP. •C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*	STEAM GRAM
	0	655											
1	5	771	0.37	0.55	0.01	0.01	0.55	0.09	0.17	8	83	35	58
2	10	814	1.15	2.05	0.03	0.04	1.67	0.33	0.61	26	181	70	125
3	15	813	1.89	3.69	0.06	0.05	2.73	0.68	1.12	46	283	105	133
4	20	857	2.45	4.81	0.07	0.06	3.60	0.97	1.51	61	360	140	260
5	25	864	2.96	5.81	0.08	0.07	4.54	1.17	1.86	74	432	176	328
6	30	865	3.44	6.70	0.08	0.09	5.56	1.28	2.18	85	499	211	397
7	35	863	3.85	7.44	0.08	0.10	6.56	1.37	2.49	94	559	246	464
8	40	855	4.21	8.03	0.08	0.11	7.61	1.44	2.83	104	617	281	532
9	45	844	4.56	8.53	0.08	0.13	8.73	1.50	3.21	113	674	316	600
10	50	830	4.88	8.98	0.08	0.15	9.91	1.55	3.60	122	731	351	667
11	55	810	5.21	9.42	0.08	0.16	11.14	1.60	4.00	132	789	386	735
12	60	796	5.53	9.93	0.08	0.18	12.31	1.64	4.39	141	847	421	802
13	65	786	5.83	10.42	0.08	0.19	13.40	1.67	4.73	149	900	456	871
14	70	778	6.12	10.76	0.08	0.20	14.44	1.70	5.00	156	947	492	938
15	75	768	6.41	11.03	0.08	0.22	15.49	1.71	5.20	162	991	527	1006
16	80	765	6.66	11.19	0.08	0.23	16.48	1.72	5.33	167	1028	562	1073
17	85	746	7.16	11.35	0.08	0.26	18.46	1.73	5.44	174	1094	597	1142
18	90	685	7.25	11.36	0.08	0.28	18.84	1.73	5.45	175	1106	632	1210
19	95	671	7.47	11.38	0.08	0.42	20.18	1.73	5.47	178	1147	667	1273
20	100	662	7.60	11.38	0.08	0.65	21.51	1.73	5.43	180	1187	702	1344
21	105	654	7.67	11.38	0.08	0.95	22.85	1.74	5.48	181	1228	737	1412

* AT 15•C AND 101.325 KPA

BASED ON SUPPLIED AIR VOLUME

RUN 27 ESTEVAN LIGNITE (CARBON AIR STEAM) 6MPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*	STEAM GRAM
	0	653											
1	5	454	0.44			0.24	1.14			5	51	35	59
2	10	862	0.94			0.47	2.28			11	83	69	119
3	15	917	1.50			0.67	3.42			18	116	104	177
4	20	950	2.07			0.82	4.56			25	129	138	238
5	25	981	3.40		0.03	1.23	5.70	0.27	0.09	46	140	173	300
6	30	898	6.41		0.12	1.39	6.84	1.00	0.36	96	169	207	340

* AT 15°C AND 101.325 KPA

BASED ON PRODUCED GAS VOLUME

RUN 27 ESTEVAN LIGNITE (CARBON AIR STEAM) 6MPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*	STEAM GRAM
	0	653											
1	5	454	0.26			0.14	0.68			3	51	35	59
2	10	862	0.62			0.31	1.50			7	83	69	119
3	15	917	1.02			0.45	2.33			12	116	104	177
4	20	950	1.19			0.52	2.66			14	129	138	238
5	25	981	1.39			0.57	2.83	0.04	0.01	17	140	173	300
6	30	898	2.06		0.03	0.61	3.09	0.20	0.07	29	169	207	340

* AT 15°C AND 101.325 KPA

BASED ON SUPPLIED AIR VOLUME

RUN 28 ESTEVAN LIGNITE (CARBON AIR STEAM) 6MPA

SAMPLE NO.	TIME MIN	TEMP. •C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*	STEAM GRAM
	0	657											
1	5	547	0.40	2.26	0.32	0.09	1.14		0.23	15	42	35	54
2	10	876	0.58	2.82	0.39	0.27	2.28		0.29	20	80	69	114
3	15	922	0.70	2.82	0.39	0.51	3.42		0.29	21	123	104	173
4	20	950	1.10	3.35	0.42	0.77	4.56	0.05	0.31	28	156	138	231
5	25	988	2.44	5.24	0.51	0.90	5.70	0.40	0.51	53	188	173	290
6	30	997	3.34	6.22	0.56	0.94	6.84	0.78	0.74	72	253	207	348
7	35	996	3.91	6.90	0.60	0.96	7.98	1.14	0.97	87	262	242	408
8	40	1003	4.41	7.98	0.63	0.98	9.12	1.50	1.22	101	311	276	466
9	45	987	4.76	8.78	0.66	1.00	10.27	1.75	1.52	112	353	311	526
10	50	952	5.01	9.07	0.67	1.02	11.41	1.90	1.84	121	402	345	582
11	55	925	5.21	9.25	0.67	1.04	12.55	1.98	2.19	129	479	380	642
12	60	908	5.37	9.35	0.67	1.05	13.69	2.02	2.55	135	502	415	700
13	65	904	5.52	9.44	0.67	1.07	14.83	2.06	2.92	142	557	449	759
14	70	896	5.66	9.55	0.68	1.09	15.97	2.09	3.30	149	609	434	818
15	75	854	5.79	9.65	0.68	1.10	17.11	2.11	3.71	156	657	518	876
16	80	828	5.93	9.83	0.68	1.12	18.25	2.14	4.13	163	695	553	935
17	85	737	6.08	10.16	0.68	1.14	19.39	2.16	4.58	170	730	537	997
18	90	679	6.22	10.42	0.68	1.16	20.53	2.18	5.03	177	768	622	1054
19	95	702	6.36	10.57	0.68	1.17	21.68	2.19	5.48	185	808	656	1111
20	100	684	6.51	10.71	0.68	1.19	22.82	2.21	5.91	192	853	691	1169
21	105	679	6.68	10.80	0.68	1.22	23.96	2.22	6.19	197	905	725	1230
22	110	672	6.86	10.84	0.68	1.29	25.10	2.22	6.33	201	952	760	1288
23	115	664	6.99	10.87	0.68	1.43	26.24	2.23	6.39	204	999	795	1346
24	120	656	7.08	10.87	0.68	1.62	27.38	2.23	6.42	205	1045	829	1405
25	125	649	7.13	10.87	0.68	1.85	28.52	2.23	6.43	206	1091	864	1565
26	135	633	7.22	10.87	0.68	2.35	30.80	2.23	6.45	207	1184	933	1581

* AT 15•C AND 101.325 KPA

BASED ON PRODUCED GAS VOLUME

RUN 28 ESTEVAN LIGNITE (CARBON AIR STEAM) 6MPA

SAMPLE NO.	TIME MIN.	TEMP. •C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*	STEAM GRAM
	0	657											
1	5	547	0.03	0.46	0.06	0.02	0.23		0.05	3	42	35	54
2	10	876	0.21	0.86	0.12	0.15	1.05		0.09	7	80	69	114
3	15	922	0.36	0.86	0.12	0.44	2.44		0.09	8	123	104	173
4	20	950	0.59	1.17	0.14	0.59	3.10	0.03	0.10	12	156	138	231
5	25	988	0.94	1.66	0.16	0.63	3.40	0.12	0.15	18	188	173	290
6	30	997	1.60	2.38	0.20	0.65	4.24	0.40	0.32	33	253	207	348
7	35	996	1.68	2.47	0.20	0.65	4.39	0.45	0.35	35	262	242	408
8	40	1003	1.98	3.13	0.22	0.67	5.08	0.67	0.51	43	311	276	466
9	45	987	2.20	3.63	0.24	0.66	5.79	0.82	0.69	50	353	311	526
10	50	952	2.43	3.89	0.25	0.70	6.85	0.97	1.00	59	402	345	582
11	55	925	2.76	4.20	0.25	0.73	8.76	1.10	1.58	71	479	380	642
12	60	908	2.85	4.25	0.25	0.73	9.37	1.12	1.77	75	502	415	700
13	65	904	3.04	4.37	0.26	0.75	10.39	1.17	2.24	83	557	449	758
14	70	896	3.21	4.50	0.26	0.78	12.22	1.20	2.70	92	609	484	818
15	75	854	3.36	4.61	0.26	0.80	13.48	1.23	3.15	99	657	518	876
16	80	828	3.47	4.77	0.26	0.81	14.44	1.25	3.51	105	695	553	936
17	85	737	3.57	4.99	0.26	0.82	15.23	1.27	3.82	110	730	587	997
18	90	673	3.69	5.20	0.26	0.84	16.14	1.28	4.18	116	763	622	1054
19	95	702	3.81	5.33	0.26	0.85	17.14	1.29	4.58	122	803	656	1111
20	100	684	3.98	5.49	0.26	0.87	18.43	1.31	5.06	130	858	691	1169
21	105	679	4.17	5.59	0.26	0.90	19.73	1.33	5.39	137	905	725	1230
22	110	672	4.40	5.65	0.26	0.99	21.18	1.33	5.56	142	952	760	1288
23	115	664	4.57	5.68	0.26	1.17	22.68	1.33	5.64	145	999	795	1346
24	120	656	4.69	5.63	0.26	1.43	24.20	1.34	5.68	147	1045	829	1405
25	125	649	4.77	5.69	0.26	1.75	25.76	1.34	5.70	148	1091	864	1665
26	135	633	4.88	5.59	0.26	2.42	28.87	1.34	5.72	150	1184	933	1581

* AT 15•C AND 101.325 KPA

BASED ON SUPPLIED AIR VOLUME

RUN 29 ESTEVAN LIGNITE (CARBON AIR STEAM) 6MPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*	STEAM GRAM
	0	657											
1	10	857	1.43			0.20	2.28	0.05	0.49	24	116	69	120
2	15	906	2.90	0.52	0.02	0.32	3.42	0.19	0.79	47	163	104	179
3	20	931	6.21	2.77	0.14	0.44	4.56	0.90	1.18	103	198	138	233
4	25	958	7.77	4.17	0.23	0.50	5.70	1.46	1.41	133	229	173	297
5	30	959	8.87	5.29	0.29	0.55	6.84	1.91	1.59	155	262	207	356
6	35	969	9.63	5.96	0.33	0.58	7.99	2.35	1.79	173	298	242	414
7	40	960	10.11	6.34	0.36	0.60	9.13	2.76	2.00	187	334	276	472
8	45	954	10.49	6.68	0.38	0.61	10.27	3.09	2.25	199	373	311	533
9	50	941	10.79	6.99	0.39	0.63	11.41	3.31	2.52	209	410	345	590
10	55	935	11.02	7.20	0.40	0.65	12.55	3.44	2.80	217	453	380	649
11	60	927	11.21	7.30	0.40	0.67	13.69	3.51	3.11	224	492	415	708
12	65	922	11.38	7.38	0.40	0.68	14.83	3.56	3.43	230	539	449	768
13	70	904	11.54	7.45	0.40	0.70	15.97	3.58	3.75	236	586	434	826
14	75	898	11.68	7.50	0.40	0.71	17.11	3.60	4.08	242	634	518	835
15	80	898	11.83	7.53	0.40	0.73	18.25	3.62	4.43	248	684	553	943
16	85	895	11.97	7.58	0.40	0.75	19.39	3.64	4.73	254	731	587	1003
17	90	893	12.12	7.64	0.40	0.77	20.53	3.66	5.15	261	780	622	1061
18	95	881	12.28	7.73	0.40	0.79	21.68	3.68	5.53	267	830	656	1120
19	100	868	12.43	7.82	0.40	0.81	22.82	3.70	5.91	274	889	691	1180
20	105	855	12.59	7.92	0.40	0.82	23.96	3.73	6.29	281	944	725	1237
21	110	825	12.75	8.02	0.40	0.84	25.10	3.75	6.68	288	1013	760	1297
22	120	705	13.10	8.35	0.40	0.88	27.38	3.79	7.47	302	1148	829	1415
23	130	658	13.56	8.90	0.40	0.92	29.66	3.85	8.25	318	1234	893	1533
24	135	635	13.83	9.20	0.40	0.94	30.80	3.87	8.55	325	1280	933	1591

* AT 15°C AND 101.325 KPA

BASED ON PRODUCED GAS VOLUME

RUN 29 ESTEVAN LIGNITE (CARBON AIR STEAM) 6MPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*	STEAM GRAM
	0	657											
1	10	857	0.79			0.11	1.26	0.03	0.27	13	116	69	120
2	15	906	1.56	0.28	0.01	0.17	1.86	0.10	0.43	25	163	104	179
3	20	931	2.18	0.69	0.03	0.20	2.07	0.23	0.50	36	193	138	238
4	25	958	2.59	1.06	0.06	0.21	2.38	0.38	0.56	44	229	173	297
5	30	959	2.96	1.44	0.08	0.23	2.76	0.54	0.62	51	262	207	356
6	35	969	3.32	1.76	0.10	0.24	3.30	0.74	0.71	60	298	242	414
7	40	960	3.59	1.97	0.11	0.25	3.94	0.97	0.84	68	334	276	472
8	45	954	3.85	2.20	0.13	0.26	4.71	1.19	1.00	76	373	311	533
9	50	941	4.05	2.41	0.13	0.27	5.49	1.35	1.19	82	410	345	590
10	55	936	4.26	2.60	0.14	0.29	6.51	1.46	1.44	89	453	380	649
11	60	927	4.43	2.69	0.14	0.30	7.52	1.53	1.71	95	492	415	708
12	65	922	4.62	2.78	0.14	0.32	8.81	1.57	2.07	103	539	449	768
13	70	904	4.80	2.86	0.15	0.34	10.12	1.61	2.45	110	586	484	826
14	75	898	4.98	2.92	0.15	0.36	11.48	1.63	2.84	117	634	518	885
15	80	898	5.15	2.96	0.15	0.38	12.92	1.65	3.27	124	684	553	943
16	85	895	5.32	3.01	0.15	0.41	14.23	1.67	3.68	132	731	587	1003
17	90	893	5.49	3.09	0.15	0.43	15.57	1.69	4.12	139	780	622	1061
18	95	881	5.68	3.19	0.15	0.45	16.91	1.72	4.56	147	830	656	1120
19	100	868	5.89	3.32	0.15	0.47	18.48	1.75	5.09	156	889	691	1180
20	105	855	6.09	3.44	0.15	0.50	19.93	1.78	5.57	165	944	725	1237
21	110	825	6.34	3.61	0.15	0.53	21.75	1.81	6.19	176	1013	760	1297
22	120	705	6.88	4.10	0.15	0.58	25.14	1.88	7.37	197	1148	829	1415
23	130	658	7.27	4.58	0.15	0.61	27.13	1.93	8.05	211	1234	898	1533
24	135	635	7.53	4.87	0.15	0.64	28.22	1.95	8.33	217	1280	933	1591

* AT 15°C AND 101.325 KPA

BASED ON SUPPLIED AIR VOLUME

RUN 30 ESTEVAN LIGNITE (PYROLYSIS) 2MPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*	STEAM GRAM
	0	817											
1	5	680	5.87	15.34	0.23	0.06	1.16	1.71	1.03	109	80	35	
2	10	795	6.85	17.88	0.27	0.07	2.32	2.11	1.22	129	142	70	
3	15	801	7.16	18.82	0.29	0.08	3.48	2.32	1.30	136	196	105	
4	20	804	7.34	19.55	0.31	0.09	4.64	2.50	1.38	142	246	140	
5	25	805	7.45	20.06	0.32	0.09	5.80	2.65	1.45	146	288	176	
6	30	807	7.50	20.34	0.33	0.09	6.96	2.75	1.50	149	326	211	
7	35	808	7.52	20.50	0.33	0.09	8.12	2.79	1.52	150	364	246	
8	40	809	7.53	20.59	0.33	0.10	9.28	2.80	1.53	150	401	281	
9	45	810	7.54	20.65	0.33	0.10	10.44	2.81	1.54	151	439	316	
10	50	811	7.54	20.69	0.33	0.10	11.59	2.81	1.54	151	476	351	
11	55	811	7.55	20.72	0.33	0.10	12.75	2.81	1.54	151	513	386	
12	60	812	7.55	20.76	0.33	0.10	13.91	2.82	1.54	151	554	421	
13	65	811	7.56	20.79	0.33	0.11	15.07	2.82	1.54	151	625	456	
14	70	811	7.56	20.80	0.33	0.11	16.23	2.82	1.55	151	663	492	

* AT 15°C AND 101.325 KPA

BASED ON PRODUCED GAS VOLUME

RUN 30 ESTEVAN LIGNITE (PYROLYSIS) 2MPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*	STEAM GRAM
	0	817											
1	5	680	0.39	1.02	0.02		0.08	0.11	0.07	7	80	35	
2	10	795	0.87	2.27	0.04	0.01	0.64	0.31	0.16	17	142	70	
3	15	801	1.13	3.06	0.05	0.02	1.62	0.49	0.23	23	196	105	
4	20	804	1.29	3.71	0.07	0.02	2.66	0.64	0.30	29	246	140	
5	25	805	1.39	4.16	0.08	0.02	3.68	0.73	0.37	32	288	176	
6	30	807	1.43	4.44	0.09	0.03	4.83	0.87	0.41	35	326	211	
7	35	808	1.46	4.62	0.09	0.03	6.15	0.92	0.44	36	364	246	
8	40	809	1.47	4.73	0.09	0.03	7.55	0.94	0.45	36	401	281	
9	45	810	1.48	4.80	0.09	0.03	9.05	0.95	0.46	37	439	316	
10	50	811	1.49	4.85	0.09	0.04	10.55	0.95	0.46	37	476	351	
11	55	811	1.50	4.90	0.09	0.04	12.08	0.95	0.46	37	513	386	
12	60	812	1.51	4.96	0.09	0.04	13.71	0.96	0.47	37	554	421	
13	65	811	1.52	5.02	0.09	0.05	16.63	0.96	0.47	38	625	456	
14	70	811	1.52	5.04	0.09	0.05	18.22	0.97	0.47	38	663	492	

* AT 15°C AND 101.325 KPA

BASED ON SUPPLIED AIR VOLUME

RUN 31 ESTEVAN LIGNITE (CARBON AIR STEAM) ~150KPA

SAMPLE NO.	TIME MIN.	TEMP. •C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*	STEAM GRAM
	0	678											
1	10	667	0.90	1.99	0.02	0.28	1.66	0.24	0.18	16	59	50	151
2	15	674	1.50	3.46	0.03	0.38	2.50	0.38	0.31	27	127	76	224
3	20	664	2.23	5.24	0.04	0.42	3.33	0.47	0.46	39	194	101	297
4	25	662	2.84	6.60	0.04	0.46	4.16	0.51	0.59	48	258	126	370
5	30	670	3.14	7.90	0.04	0.49	4.99	0.53	0.71	54	319	151	444
6	35	656	3.41	9.82	0.04	0.53	5.83	0.54	0.80	58	364	176	519
7	40	648	4.41	13.16	0.04	0.57	6.66	0.56	0.83	71	391	202	530
8	45	644	6.21	17.90	0.04	0.62	7.49	0.59	1.08	96	409	227	661
9	50	673	7.74	21.68	0.04	0.68	8.69	0.63	1.32	117	421	263	661
10	55	705	8.28	22.68	0.04	0.73	9.89	0.65	1.57	127	429	300	661
11	60	710	8.57	23.11	0.04	0.78	11.09	0.66	1.82	134	436	336	661
12	65	693	8.69	23.35	0.04	0.95	12.36	0.67	1.98	137	607	374	827
13	70	685	8.91	23.72	0.04	1.14	13.62	0.67	2.05	141	673	412	893
14	75	645	9.15	24.01	0.04	1.35	14.88	0.67	2.08	144	715	451	971
15	80	637	9.19	24.01	0.04	1.66	16.14	0.67	2.08	144	753	489	1046
16	85	636	9.21	24.01	0.04	1.97	17.41	0.67	2.08	145	791	527	1115

* AT 15•C AND 101.325 KPA

BASED ON PRODUCED GAS VOLUME

RUN 31 ESTEVAN LIGNITE (CARBON AIR STEAM) ~150KPA

SAMPLE NO.	TIME MIN.	TEMP. °C	ACCUMULATED MOLES CO2	H2	C2	O2	N2	CH4	CO	CARBON EQUIV. GRAM	GAS (L)*	AIR (L)*	STEAM GRAM
	0	678											
1	10	667	0.21	0.47	0.01	0.07	0.40	0.06	0.04	4	59	50	151
2	15	674	0.74	1.76	0.02	0.16	1.12	0.18	0.15	13	127	76	224
3	20	664	1.31	3.14	0.02	0.13	1.77	0.25	0.27	22	194	101	297
4	25	662	1.86	4.37	0.02	0.22	2.52	0.29	0.39	31	258	126	370
5	30	670	2.15	5.64	0.02	0.25	3.34	0.31	0.51	36	319	151	444
6	35	656	2.32	6.82	0.02	0.28	3.35	0.31	0.56	39	364	176	519
7	40	648	2.53	7.53	0.02	0.29	4.02	0.32	0.58	42	391	202	590
8	45	644	2.71	8.00	0.02	0.29	4.11	0.32	0.60	44	409	227	661
9	50	673	2.82	8.27	0.02	0.29	4.19	0.32	0.62	46	421	263	661
10	55	705	2.88	8.39	0.02	0.30	4.33	0.33	0.65	47	429	300	661
11	60	710	2.91	8.44	0.02	0.31	4.48	0.33	0.68	43	436	336	661
12	65	639	3.35	9.33	0.03	0.95	9.17	0.35	1.24	60	607	374	827
13	70	685	3.65	9.30	0.03	1.19	10.82	0.35	1.34	65	673	412	898
14	75	645	3.86	10.07	0.03	1.38	11.92	0.35	1.37	68	715	451	971
15	80	637	3.90	10.07	0.03	1.69	13.19	0.35	1.37	68	753	489	1046
16	85	636	3.92	10.07	0.03	1.99	14.45	0.35	1.37	68	791	527	1115

* AT 15°C AND 101.325 KPA

Appendix 4 COMPUTER PROGRAMS

For a description, see function DESCRIBE.

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      DESCRIBE
THIS IS A COLLECTION OF PROGRAMS WHICH CALCULATE THE HEATING
VALUE IN MJ/M3 FOR A GIVEN COMPOSITION OF GASEOUS COMPOUNDS ACCORDING
TO THE METHODS OUTLINED BY THE  AMERICAN GAS ASSOCIATION, INC., GAS
MEASUREMENT COMMITTEE REPORT NO. 5.
THE PROGRAM ACCEPTS AS INPUT EITHER PEAK AREAS AS OBTAINED BY GAS-
CHROMATOGRAPH OR VOLUME PERCENT. IN THE LATTER CASE THE DETECTOR RES-
PONSE FACTORS ARE SET TO 1.
THE PROGRAMS ALSO CALCULATE THE TOTAL AMOUNT OF CARBON CONSUMED DURING A
GASIFICATION RUN, BASED ON EITHER THE SUPPLIED AIR VOLUME (USING NITROGEN
AS A TRACER GAS) OR BASED ON THE VOLUME OF GAS PRODUCED.
 MORE INFORMATION IS GIVEN IN THE ----INFO  PROGRAMS WHICH CONTAIN MORE
DETAILS ON HOW TO USE THE PROGRAMS.  THESE ARE:

ENTERINFO          HOW TO ENTER THE DATA.

PRINTINFO          HOW TO LIST THE RESULTS.

WORKSPACEINFO      HOW TO STORE YOUR DATA IN A SEPARATE WORKSPACE.

GLOBALINFO         A LIST OF GLOBAL VARIABLES WHICH MUST EXIST.

PROGRAMMERINFO     SOME HINTS ON THE STRUCTURE OF THIS PACKAGE, WHICH
                   MAY HELP TO MODIFY THE PROGRAMS.
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     ENTERINFO

GASIFICATION    THIS PROGRAM WILL INDICATE TO YOU WHICH PARAMETERS ARE TO BE
                INPUT AT A GIVEN TIME.
                THE INPUT CONSISTS OF EITHER PEAK AREAS OR A VOLUME PERCENTAGE
                FOR THE FOLLOWING GASEOUS COMPONENTS:
                CO2 H2 C2 O2 N2 CH4 CO.
                THIS IS THE ORDER IN WHICH THE COMPONENTS ELUTE FROM A FISHER
                MODEL 1200 GASPARTITIONER. FOR EXTENSION OR EXCHANGE SEE
                PROGRAMMER INFO.
                THE SECOND INPUT IS: AIR FLOWRATE (IN SCFM), PRODUCED GAS
                VOLUME (IN CF), TIME LAP BETWEEN SAMPLE POINTS (IN MIN.),
                INTERIOR REACTOR TEMPERATURE (IN °C) AND THE WEIGHT OF THE
                WATER RESERVOIR AT TIME T (IN G.).

CONSUMPTION     THIS PROGRAM WILL CALCULATE THE AMOUNT OF CARBON CONSUMED
                ACCORDING TO THE TWO METHODS AS OUTLINED IN DESCRIBE.
                THE PROGAM REQUIRES RUNNING OF GASIFICATION AS A PREREQUISITE,
                OR THE GROUP  RESULTS  TO BE COPIED FROM A WORKSPACE.

OUTPUT1         THIS PROGRAM OUTPUTS RESULTS FROM  GASIFICATION, I.E. GAS-
                COMPOSITION AND HEATING VALUE.

OUTPUT2         OUTPUTS RESULTS FROM  CONSUMPTION  BASED ON SUPPLIED AIR VOLUME.

OUTPUT3         OUTPUTS RESULTS FROM  CONSUMPTION  BASED ON PRODUCED GAS VOLUME.

EDIT N          THIS PROGRAM ALLOWS FOR CORRECTION TO BE MADE AS A RESULT OF
                KEYPUNCH ERRORS. N  IS THE SAMPLE NUMBER TO BE CORRECTED.
     PRINTINFO

SEE ENTERINFO  OUPUT1 OUTPUT2 AND OUTPUT3.


     GLOBALINFO

THE FOLLOWING GLOBAL VARIABLES MUST EXIST IN YOUR WORKSPACE BEFORE
ATTEMPTING TO EXCECUTE THE PROGRAMS:

RF           DETECTOR RESPONSE FACTORS FOR EACH COMPONENT IN THE GAS MIXTURE.
             IF PEAK AREAS  ARE NOT USED AS INPUT. BUT VOLUME PERCENTAGES ARE
             USED INSTEAD, THE COMPONENTS IN RF MUST BE SET TO 1.

COMPONENTS   THIS IS A GROUP NAME CONTAINING LOCKED FUNCTIONS WITH SPECIFIC
             HEAT VALUES AND SPECIFIC GRAVITY VALUES FOR THE PURE COMPONENTS.
             THE VALUES ARE THOSE LISTED IN THE: AMERICAN GAS ASSOCIATION.
             INC., GAS MEASUREMENT COMMITTEE REPORT NO. 5.
             THE MEMBERS OF THE GROUP ARE:
             CH4 CO CO2 C2 C3 C6 C7 C8 H2 H2S IC4 IC5 NC4 NC5 N2 O2 .

RESULTS      THESE ARE THE GLOBAL VARIABLES CREATED BY GASIFICATION  AND
             CAN BE USED TO STORE THE DATA IN A SEPARATE WORKSPACE.
             THE MEMBERS OF THE GROUP ARE:
             MOLECOMP NUMBER TCARBON TEMP TINV TSTEAM CONSUMPTION FVOL

             HEADER HEATVALUE IVOL
             THESE ARE ALL CREATED DURING EXECUTION OF GASIFICATION.
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      WORKSPACEINFO

THE GROUP  RESULTS  CAN BE USED TO TRANSFER THE DATA TO A SEPERATE
WORKSPACE.  AFTER COPYING RESULTS BACK FOR LISTING THE PROGRAM
 CONSUMPTION  MUST BE RERUN.
THE MEMBERS IN THE GROUP ARE LISTED IN GLOBALINFO.


      PROGRAMMERINFO

TO INTERCHANGE OR EXPAND THE TYPES OF GASEOUS COMPONENTS.CHANGES ARE REQUIRED
IN:
SPHEAT[1⎕]. INITIALYZE[8⎕12]. INPUT[4⎕55]. VOLPERCENT[1⎕16]. CARBON[1⎕] AND
CONSUMPTION[2⎕19].
COMPONENT ADDITION, DELETION OR EXCHANGE IS REQUIRED ONLY IN  SPHEAT[1⎕].
THE OTHER REQUIRED A SIZE CHANGE AT THE INDICATED LINE NUMBERS.
THE FUNCTION ΔFMT IS A XEROX FORMATING FUNCTION AND IS USED IN OUTPUT1[7⎕49]
OUTPUT2[8⎕49] AND OUTPUT[3⎕49]. THIS MAY BE REPLACED BY THE FORMATTING FUNCTION
AVAILABLE AT YOUR INSTALATION.
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     ∇ GASIFICATION;A;AREAS
[1]    TSAMPLES←INITIALYZE
[2]    A←0
[3]    ΔA:→ENDΔA WHEN TSAMPLES<A←A+1
[4]    AREAS←INPUT A
[5]    A CALCULATE AREAS
[6]    →ΔA
[7]    ENDΔA:TSTEAM←WATER[1]-WATER
     ∇


     ∇ AREA←INPUT N;PEAK;ERR;CF;I1;LITERS
[1]    GC:'ENTER THE PEAK AREAS FOR SAMPLE NO.: ';(N-1)
[2]    PEAK←⍳0
[3]    PEAK←PEAK,⎕
[4]    →GC IF ERR←'SEVEN AREAS REQUIRED AS INPUT'ERROR 7≠ρ,
       PEAK
[5]    →GC IF ERR←'NEGATIVE AREA DETECTED'ERROR 1∊0>PEAK
[6]    AREA←PEAK
[7]    V1:'ENTER: AIR FLOWRATE, GAS VOLUME, TIME LAP, REACTOR T
       EMP., WEIGHT WATER       '
[8]    I1←⍳0
[9]    I1←I1,⎕
[10]   →V1 IF ERR←'FIVE VALUES REQUIRED'ERROR 5≠ρ,I1
[11]   →V1 IF ERR←'NEGATIVE VALUE DETECTED'ERROR 1∊0>I1
[12]   LITERS←I1[2]×28.31605
[13]   →FIRST IF 1=N
[14]   →V1 IF ERR←'GAS PRODUCED: VOLUME LESS THAN PREVIOUS VOLU
       ME'ERROR FVOL[N-1]>LITERS
[15]   FIRST:FVOL[N]←LITERS
[16]   TINV[N]←I1[3]
[17]   IVOL[N]←I1[1]×I1[3]×28.31605
[18]   TEMP[N]←I1[4]
[19]   WATER[N]←I1[5]
     ∇


     ∇ Z̲←INITIALYZE;R1;R2;ERR
[1]    'ENTER HEADER IDENTIFICATION
              RUN NO. AND TYPE'
[2]    HEADER←⍞
[3]    SAMP:'ENTER THE NO. OF SAMPLES TAKEN DURING THIS RUN'
[4]    Z̲←⎕+1
[5]    →SAMP IF ERR←'NUMBER NOT A SCALAR'ERROR 1≠ρ,Z̲
[6]    →SAMP IF ERR←'NUMBER NOT POSITIVE'ERROR 0≥Z̲
[7]    →SAMP IF ERR←'NUMBER NOT INTEGER'ERROR Z̲≠⌊Z̲
[8]    R2←Z̲,7
[9]    FVOL←NUMBER←TINV←IVOL←TEMP←HEATVALUE←TSTEAM←WATER←Z̲ρ0
[10]   COMPOSITION←R2ρ0
     ∇
```

```
    ∇ N CALCULATE AREA;AIRVOL;COMP
[1]   →SKIP IF 1=N
[2]   NUMBER[N]←N-1
[3]   COMPOSITION[N;]←ANALYSIS←RF NORMALYZE AREA
[4]   HEATVALUE[N]←HEATV←SPHEAT ANALYSIS
[5]   SKIP:→0
    ∇


    ∇ VOLPERCENT←RFACTOR NORMALYZE AREA;INFO;PROD
[1]   INFO←⍉(2 7⍴(AREA,RFACTOR))
[2]   VOLPERCENT←100×PROD÷(+/PROD←INFO[;1]×INFO[;2])
    ∇


    ∇ HEATVAL←SPHEAT GASCOMP;INFO;INERTS;EXT;ZZ
[1]   INFO←0 1 1\(7 2⍴(CO2,H2,C2,O2,N2,CH4,CO))
[2]   INFO[;1]←7 1⍴GASCOMP
[3]   EXT←(INFO[;1]÷100)+.×INFO[;2 3]
[4]   INERTS←+/(INFO[;1]÷100)×(0=INFO[;2])
[5]   ZZ←1.004-(0.0101×EXT[2])+(0.007×INERTS)
[6]   HEATVAL←0.03727×((+/EXT[1])÷ZZ)
    ∇


    ∇ TEXT PERROR CONDITION
[1]   →(1≠∨/,CONDITION×CONDITION=1)/0
[2]   TEXT;'   ERROR'
[3]   →
    ∇


    ∇ Z←LABEL IF CONDITION
[1]   'IF: CONDITION RANK'PERROR 1≠⍴,CONDITION
[2]   'IF: LABEL RANK'PERROR 1≠⍴,LABEL
[3]   'IF: DOMAIN'PERROR~CONDITION∊0 1
[4]   Z←CONDITION/LABEL
    ∇


    ∇ Z←LABEL WHEN CONDITION
[1]   'IF: CONDITION RANK'PERROR 1≠⍴,CONDITION
[2]   'IF: LABEL RANK'PERROR 1≠⍴,LABEL
[3]   'IF: DOMAIN'PERROR~CONDITION∊0 1
[4]   Z←CONDITION/LABEL
    ∇
```

```
     ∇ CONSUMPTION;A;NN;X;COMP;AV;TSAMPLES;FRACT
[1]    TSAMPLES←⍴(NUMBER)
[2]    NN←TSAMPLES,7
[3]    ICARBON←FCARBON←TSAMPLES⍴0
[4]    IMCOMP←FMCOMP←NN⍴0
[5]    A←0
[6]    ΔA:→ENDΔA WHEN TSAMPLES<A←A+1
[7]    →SKIP IF A=1
[8]    X←(A-1),A
[9]    COMP←COMPOSITION[X;]÷100
[10]   FRACT←(÷AV[5])×AV←(+/[1]COMP)÷2
[11]   IMCOMP[A;]←FRACT×NN←IVOL[A]×0.78084÷23.6455
[12]   FMCOMP[A;]←FRACT×NN←(FVOL[A]-FVOL[A-1])×AV[5]÷23.6455
[13]   ICARBON[A]←CEQUIV IMCOMP[A;]
[14]   FCARBON[A]←CEQUIV FMCOMP[A;]
[15]   SKIP:→ΔA
[16]   ENDΔA:'READY'
     ∇
```

```
     ∇ CARBON←CEQUIV MOLECOMP
[1]    CARBON←12×+/(MOLECOMP×1 0 2 0 0 1 1)
     ∇
```

```
     ∇ Z←TEXT ERROR CONDITION
[1]    Z←0
[2]    →(1≠∨/,CONDITION×CONDITION=1)/0
[3]    'ERROR:  ';TEXT
[4]    Z←1
     ∇
```

```
     ∇ Z←REPLACE COMP;ZZ;ZVECT
[1]    ZZ←(,Z)/⍳(×/⍴Z←((COMP<0.09)∧(COMP>0.001)))
[2]    ZVECT←,COMP
[3]    ZVECT[ZZ]←¯0.1
[4]    Z←(⍴COMP)⍴ZVECT
     ∇
```

```
    ∇ OUTPUT1;COMPOSIT
[1]   COMPOSIT←REPLACE COMPOSITION
[2]   ,'A1'ΔFMT HEADER
[3]   ' '
[4]   ,'A1'ΔFMT'                      TIME  TEMP.       COMPOSITION IN
     VOLUME PERCENT                    SPECIFIC HEAT   '
[5]   ,'A1'ΔFMT'SAMPLE NO.      MIN.    •C          CO2    H2    C
     2    O2    N2   CH4   CO             MJ/M3  * '
[6]   '   '
[7]   'BI3,X6,I4,X3,I4,X4,7BM⎕< ⎕F6.1,X6,BF8.3'ΔFMT(NUMBER;+\
     TINV;TEMP;COMPOSIT;HEATVALUE)
[8]   ' '
[9]   '  *  AT 15•C AND 101.325 KPA'
    ∇


    ∇ OUTPUT2
[1]   'BASED ON SUPPLIED AIR VOLUME'
[2]   ' '
[3]   ,'A1'ΔFMT HEADER
[4]   ' '
[5]   ,'A1'ΔFMT'                      TIME  TEMP.       ACCUMULATED MO
     LES                             CARBON EQUIV.        GAS
      AIR    STEAM'
[6]   ,'A1'ΔFMT'SAMPLE NO.      MIN.    •C          CO2    H2    C
     2    O2    N2   CH4   CO             GRAM             (L)*
      (L)*    GRAM '
[7]   ' '
[8]   'BI3,X6,I4,X3,I4,X4,7BF6.2,X6,BI6,X7,3BI8'ΔFMT(NUMBER;+\
     TINV;TEMP;+\[1]IMCOMP;+\ICARBON;FVOL;+\IVOL;TSTEAM)
[9]   ' '
[10]  '  *  AT 15•C AND 101.325 KPA'
    ∇


    ∇ OUTPUT3
[1]   'BASED ON PRODUCED GAS VOLUME'
[2]   ' '
[3]   ,'A1'ΔFMT HEADER
[4]   ' '
[5]   ,'A1'ΔFMT'                      TIME  TEMP.       ACCUMULATED MO
     LES                             CARBON EQUIV.        GAS
      AIR    STEAM'
[6]   ,'A1'ΔFMT'SAMPLE NO.      MIN.    •C          CO2    H2    C
     2    O2    N2   CH4   CO             GRAM             (L)*
      (L)*    GRAM '
[7]   ' '
[8]   'BI3,X6,I4,X3,I4,X4,7BF6.2,X6,BI6,X7,3BI8'ΔFMT(NUMBER;+\
     TINV;TEMP;+\[1]FMCOMP;+\FCARBON;FVOL;+\IVOL;TSTEAM)
[9]   ' '
[10]  '  *  AT 15•C AND 101.325 KPA'
    ∇
    ∇ EDIT N;AREAS
[1]   N←N+1
[2]   AREAS←INPUT N
[3]   ⍝ CALCULATE AREAS
[4]   TSTEAM←WATER[1]-WATER
    ∇
```

The following functions were used for runs 12 - 20.

```
    ∇ Z←DIOXIDE VOLCMP;DIOX
[1]   DIOX←(VOLCMP[5]×0.2805)-(VOLCMP[4]+0.5×VOLCMP[7])
[2]   VOLCMP[1]←DIOX×(0≤DIOX)
[3]   Z←100×VOLCMP÷+/VOLCMP
    ∇
```

```
    ∇ VOLPERCENT←RFACTOR NORMALIZE AREA;INFO;PROD
[1]   INFO←⍉(2 7⍴(AREA,RFACTOR))
[2]   VOLPERCENT←100×PROD÷(+/PROD←INFO[;1]×INFO[;2])
[3]   VOLPERCENT←DIOXIDE VOLPERCENT
    ∇
```

Appendix 5 PETROGRAPHIC STUDIES OF LIGNITE COALS AND GASIFICATION CHARS

February 1979

Energy Research Unit
University of Regina
Regina, Saskatchewan

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PETROGRAPHIC STUDIES OF LIGNITE COALS

and

GASIFICATION CHARS

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Definitions

Reactivity: refers to - A loss of volatile matter

A loss of hydrogen

An increase in carbon content

An increase in calorific value

Which is reflected petrologically in a large increase in reflectance (R_0) of the huminites and liptinites.

Maceral: - individual microscopical constituent of coal which is analogous to the individual mineral constituents of a crystalline rock.

ABSTRACT

The lignite coals of Estevan and Shaunavon have attained hard brown coal rank and contain larger amounts of volatile matter and hydrogen than bituminous coals, suggesting that the lignites could be a potential source of substitute natural gas. The nature and percentage yield of volatile materials evolved on gasification of the lignites depends upon the nature of the microscopical coal constituents or coal macerals.

The preliminary petrological study carried out on samples from Estevan and Shaunavon involved quantitative microscopical analyses of fresh coal samples to indicate the proportions of macerals present in the coal. Special attention was given to the content of macerals which will react most readily to release volatile products upon gasification. Microscopical observations were conducted on chars of gasification tests on a sample of Estevan lignite gasified under different conditions in an attempt to show which of the coal constituents react most completely.

Estevan and Shaunavon lignites were found to be relatively rich in the hydrogen-rich liptinite components, but these constitute a small proportion of coal. Most of the coal comprises structured and groundmass huminite and a smaller proportion of unstructured material. Examination of chars from gasified Estevan No. 1 sample shows that the reactivity of structured huminite and liptinite macerals is high in all three gasification tests but groundmass huminite reacts to a greater degree when gasified using air. The reactivity of the groundmass material appears to depend also upon the nature of other coal macerals embedded in it, being higher when it contains very reactive constituents.

Petrological analysis thus facilitates the initial assessment of the gasification potential of the coal and can be used to monitor the reactivity of coal constituents under different conditions of gasification.

INTRODUCTION

Purpose

For many years bituminous coals and anthracites have served as the raw material for the production of thermal power, for coke for the steel industry and for the petrochemical industry. As a result, the study of coals and their lithological properties has been directed towards bituminous coals and vast reserves of lignite coal have, until recently, remained unworked and unstudied because they are less suited to such industrial usage. Saskatchewan has estimated lignite resources at strippable depths of 8.4 billion tons and as the need to find additional energy resources for the future grows, so does the need to find successful methods to utilise the provinces resources. This necessitates a comprehensive study of the lignite itself which calls in turn, for a petrological knowledge of the coal. Research into the chemical and physical properties of lignite suggest that it is more suited to gasification and the production of substitute natural gas (S.N.G.) than black coals. It is hoped that petrological analysis of lignite will provide a rapid, inexpensive optical method of determining those best suited for gasification.

Tasks

This report is concerned with a preliminary study of lignite deposits from Saskatchewan during which the following tasks have been undertaken:

1. To identifiy the microscopical constituents of the coal from prepared samples before and after gasification tests.
2. To assign names to these constituents adhering, as far as possible, to the system of nomenclature adopted by the International Committee for Coal Petrology.

3. To conduct a literature search and study regarding lignite classification and the use of petrology in lignite assessment.
4. To consult with prominant workers in the field of lignite research namely:

   Dr. B.N. Nandi, CanMet, Ottawa
   Dr. Alex Cameron, I.S.P.G., Geol. Surv. Can., Calgary
   Dr. D. Marchioni, I.S.P.G., Geol. Surv. Can., Calgary
   Dr. F. Ting, University of West Virginia, Morgantown, W. Va.

5. To apply the results of the petrological study to the assessment of lignite as a potential source of S.N.G.

The study leading to this report was conducted by Mrs. J. Johnson of the Energy Research Unit, University of Regina, under contract to the Saskatchewan Power Corporation from the period May 1st - October 31, 1978. Samples of fresh coal and chars from gasification tests were supplied by the Research and Development Centre, Saskatchewan Power Corporation. Preparation and microscopical equipment was supplied by the Energy Research Unit, University of Regina.

Nomenclature

It is imperative in a study of this nature to use standardised methods of preparation, observation, analysis and nomenclature. Hence A.S.T.M. [1] methods and nomenclature adopted by the I.C.C.P. [2] have been applied in this case.

---

[1] American Society for Testing and Materials

[2] International Committee for Coal Petrology

By observing coal under a microscope it is possible to recognise both inorganic and organic constituents. The inorganic portion is referred to as mineral matter which constitutes anything that is not organically derived from vegetable matter and includes silica (quartz), clay minerals and minor amounts of ore minerals such as pyrite, limonite, etc. The organic constituents which make up the coal are referred to as macerals. These are individual constituents which are analogous to the minerals making up a rock. The macerals can be divided into groups on the basis of their reactivity and hence their chemical and physical properties. The three main maceral groups present in both bituminous coals and lignites are the Inertinite group, the Huminite group and the Liptinite group. The Inertinite group, as the name suggests, is a group of relatively unreactive macerals which, because they are oxidised or 'charred' before they were incorporated into the coal in the initial peat stage change very little with maturity. The Huminite and Liptinite group are the reactive [3/] constituents, Liptinites being more reactive than Huminites. The nature of the reactivity also changes as the chemistry changes throughout the coal rank range from soft brown coal to anthracite. The same liptinite macerals are present in brown coal and in bituminous coals but the huminites are greater in number and complexity in the brown coal stage. A classification scheme for brown coal macerals is given in Table I.

3/Reactive in the sense that upon exposure to heat or pressure the constituents will readily give off volatile material thereby increasing the carbon content.

TABLE I. SUMMARY OF THE MACERALS OF BROWN COALS

(adapted from I.C.C.P. Handbook of Coal Petrology)

Maceral Group	Maceral Subgroup	Maceral	Submaceral +
Huminite	Humotelinite (Structured)	Textinite	
		Ulminite	Texto-Ulminite Eu-Ulminite
	Humodetrinite (Groundmass)	Attrinite	
		Densinite	
	Humocollinite (Unstructured)	Gelinite	Phlobaphinite Pseudophlobaphinite
		Corpohuminite	
Liptinite		Sporinite	
		Cutinite	
		Resinite	
		Suberinite	
		Alginite	
		Liptodetrinite	
		Chlorophyllinite	
Inertinite		Fusinite	
		Semifusinite	
		Macrinite	
		Sclerotinite	
		Inertodetrinite	

+ incomplete, can be expanded as desired

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Five main parameters are used to define coal rank ... changing as follows as rank increases from soft brown coal to anthracite.

1) decrease in volatile matter yield
2) decrease in the hydrogen content
3) increase in calorific value
4) increase in carbon content
5) increase in reflectance

Because the Shaunavon and Estevan coals are at the brown coal rank where the volatile matter yield and hydrogen content are greatest, it is appropriate that their value as potential sources of substitute natural gas be investigated.

Changes during the artificial process of gasification are similar in some respects to changes in chemical constitution of the microscopical constituents that occurs during the natural coalification process so that a study of the microscopical constituents is important as a means of predicting the reactivity of the coal. A study of chars and sinters enables one to estimate those macerals which react most completely under different gasification conditions.

The Shaunavon and Estevan coals contain similar coal macerals in varying proportions. The Estevan coals are dominantly made up of structured huminite material, mainly of the eu-ulminite type with smaller amounts of texto-ulminite and textinite. The amount of unstructured material is low but the amount of groundmass material, structured but detrital, is approximately equal to the structured nondetrital portion. The liptinite component can be as much as 20% which is high. The proportions of huminite and liptinite macerals (those which on gasification will be responsible for the production of volatile hydrocarbons) are high. The inert and mineral matter contents are relatively low and can probably be separated from the coal in order to reduce their retarding effects on the coals reactivity.

The chars of three gasification tests on the Utility 1 sample from Estevan indicate that the coal reacts most completely using air to gasify the coal. This char (No 11) contains the least amount of unburnt coal and the reflectance of the macerals increased to that of the highly reflecting maceral fusinite indicating that they changed chemically by the release of volatile materials. It is concluded that a petrographic study of this nature is imperative in assessing the economic potential of a coal and that the volumetric analysis of the microscopical constituents of coal (coal macerals) will provide a very useful, rapid method of predicting the reactivity of a coal on gasification.

In this report the use of petrological assessment of coal has been demonstrated on a relatively small number of samples from a few localities only. It recommended that future work of a more detailed nature should be carried out. This work should include:

1. Maceral analyses of coals from a single seam which has been logged in detail in order to predict which parts of the seam are most suitable for gasification. Both lateral and vertical variations can be large within a single seam.
2. Analyses of more char samples in order to assess more accurately the conditions best suited to obtain maximum reactivity of the coal and to qualify the findings of this report.
3. Maceral analysis and char samples from lignite of a different maceral

composition be analysed in order to test the hypothesis that the volatile matter yield and hence the response of the coal to gasification depends on the proportion of (structured + groundmass + liptinite) macerals to (unstructured + inert) macerals.

PETROLOGICAL STUDY

Previous Work

Lignite petrology - Jacob (1961) discussed the petrographic descriptions of soft brown coal and reported that terms relating to bituminous coals could not adequately be applied to brown coals in the description of huminites. The structured component he called xylinite, the unstructured material he designated dopplinerite, and the groundmass material he called detrinite. These terms have not been used in this work since they imply a definite genetic derivation.

In the study of bituminous coals it was found by Hoffman and Jenkner (1932) that the reflectance of the vitrinite component could be used to define the rank of the coal. Teichmuller & Teichmuller (1966) have showed that reflectance has been a useful tool in the assessment of coal rank in the high volatile bituminous coal range and can be directly correlated with other chemical parameters eg. volatile matter and hydrogen content and therefore a useful prediction method in coal technology. However, Teichmuller and McCartney (1972) have shown that there is no connection between the chemical properties of brown coal and reflectance, and Marchioni (1978) showed that there is no direct correlation between reflectance and volatile matter content.

Coal chars - Various workers have examined the chars of heated bituminous coals: Murchison and Goodarzi (1975, 1976) described the plant-cell structures preserved in carbonized vitrinite and changes in the optical properties and Marshall and Murchison (1971) described changes in the reflectance of carbonized vitrinites. Nandi, et al. (1977) showed that on combustion, coals with a high inert content produce fly ash with high levels of unburnt carbon and that higher temperatures, higher exess-air levels and longer residence times were required to achieve combustion efficiency. The work was performed on bituminous coal but similar observations were made on lignite chars resulting from gasification.

Saskatchewan lignite - Cameron and Birmingham (1971) sampled lignite from the Klimax mine of the Battle River Coal Company and analysed one of the four seams of the Ravenscrag Formation (Palaeocene) both petrographically and chemically. Hydrogen content and volatile matter content were greatest in the lignites of the upper part of the seam which corresponded petrographically with those richest in structured huminite and groundmass huminte components. The lignite was low in volatile matter yield and hydrogen yield where the percentage of inertinite macerals was high. The maceral descriptions given were based on the standard I.C.C.P. nomenclature for brown coal dividing the huminites on the basis of structure: no structure: groundmass types.

Broughton (1972) described the petrology of the Estevan No. 3 seam, basing his analysis on thin sections of lignite coal. This method is very useful for analysis of the huminite components of coal and requires a more botanical approach. Moreover a comparison between the analyses in this report and those of Broughton's thin section analyses shows reasonable agreement. Ting (1972), using thin sections, described lignites in North Dakota (probably of similar origin to the Estevan coals) from a botanical point of view, attempted to recognise the primary flora, and reconstructed the environment of deposition on this basis.

Approach

Coal microscopy is a useful analytical tool in the field of bituminous coal research. Quantitative analysis of the coal constituents is employed in the prediction of coal reactivity during technological processes such as coking. It is foreseeable that the same methods can be adopted for use in predicting the reactivity of lignite coal, particularly in the process of gasification.

The chemical reactivity of a coal depends upon:

1. The relative proportion of the coal constituents or macerals.
2. The origin of the macerals before they found their way into the peat, i.e. the nature of the original vegetable matter, and which anatomical parts of the plant were incorporated into the coal.
3. Rates of biochemical and geochemical change taking place on burial.

Such questions can be answered by petrological analysis. The changes which occur during the coalification process are such that resistant waxy materials, such as those which constitute the Liptinite group of macerals, resist decay at low temperatures but when either heated artificially or geologically they will carbonise, that is they will lose the hydrocarbon side groups from within the basically aromatic coal structure (Fig. 1). 4/ The original materials from which the Huminite macerals are derived are already changed to some degree by the time they reach the coal stage and have lost some of the peripheral hydrocarbon groups as volatiles. Hence they are less reactive

---

4/ On heating they release 50-100% by volume of hydrogen-rich volatiles.

than the liptinite macerals, although they do release volatiles when heated. The Inertinite group of macerals change little from the time that they were incorporated into the peat until the coal reaches anthracitic rank. They are examples of fossil charcoal and hence react little to heating.

Consequently the coal constituents most likely to produce volatile gaseous hydrocarbons on heating are the liptinites. In most coals and lignite their volumetric proportions are much lower than the other macerals. The most abundant macerals in both black coal and lignites are those of the huminite group. It is thought that the huminite macerals which have retained their structure into the coal stage are those which will react most readily and produce gaseous products when heated. It is therefore the aim of this study to test this theory by assessing the proportion of structured to unstructured huminite and the proportion of liptinite in the coal which will gasify the most readily (see Figs. 2, 3).

Details of maceral description, properties, chemical constitution and practical importance are listed in Appendix I.

Sample Localities

Samples were collected from the Shaunavon and Estevan coalfields of Saskatchewan. The Shaunavon samples were made available by the Saskatchewan Power Corporation. The Estevan samples were collected by Dr. S. Van Der Heijden, Sask. Power Corp. and Mr. R. Neufeld of the University of Regina.

Estevan coalfield - Samples were collected from five mines in the Estevan area shown in Figure 4.

1. Boundary Dam Mine, Manitoba and Saskatchewan Coal Company.
   Samples: M & S 1-4
   M & S 1 & 2: - 1.3 m from the top of the Estevan seam
   M & S 3: - 24 cm from top of the seam
   M & S 4: - 1.6 m from top of seam

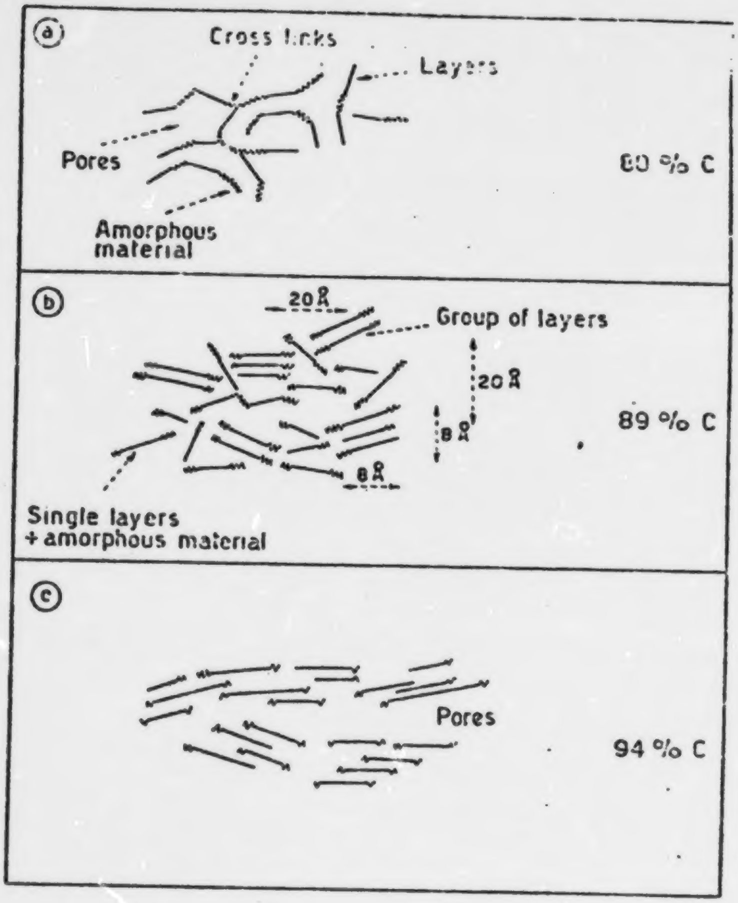
ⓐ
Cross links
Layers
Pores
80 % C
Amorphous material
ⓑ
20 Å
Group of layers
20 Å
8 Å
89 % C
8 Å
Single layers + amorphous material
ⓒ
Pores
94 % C

Figure 1: Structural model of coal (Hirsch 1954).

(a) = 'open structure'
(b) = 'liquid structure'
(c) = 'anthracitic structure'

∧∧∧∧ = Amorphous material refers to straight and branched-chain hydrocarbons which are numerous at lower rank (fig. (a) at 80%C). These are reduced at higher rank (fig. (c) at 94%C) and released as volatiles on heating.

—— = Aromatic lamellae

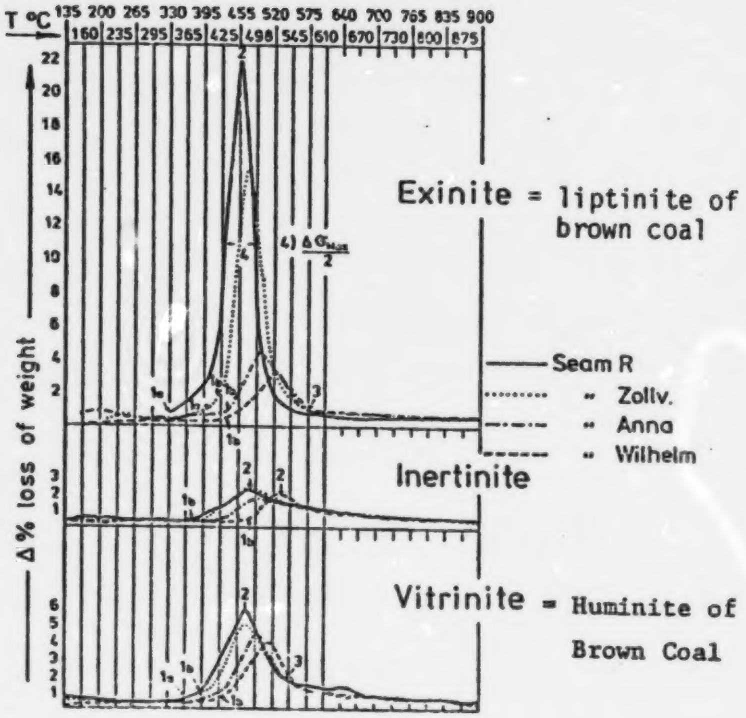

Figure 2: Degasification of the three maceral groups as a function of temperature. (adapted from Kröger, 1958).

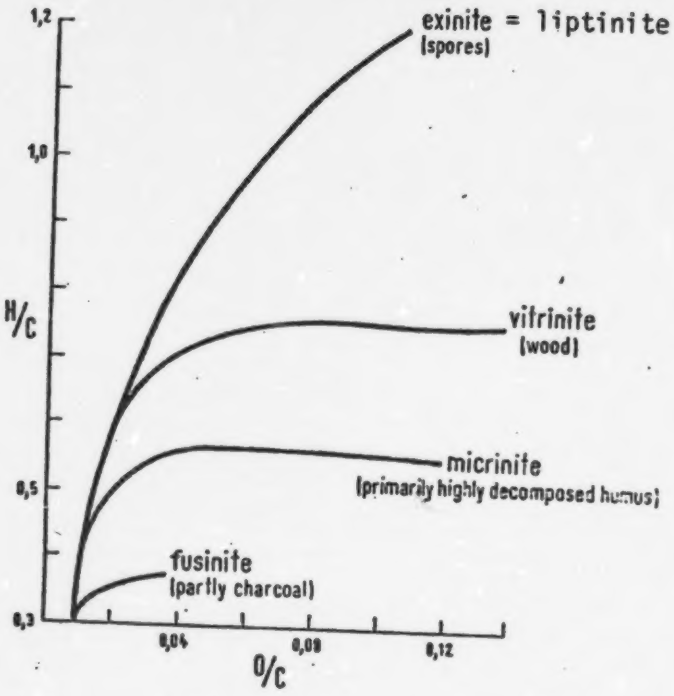

Figure 3:

Coalification tracks of different coal macerals based on H/C:O/C atomic ratios (after Dormans et al., 1957).

With increasing coal rank or artificial coalification the H/C:OC ratio generally decreases. Hydrogen is released as volatile material (particularly from exinite) and oxygen is given off as CO_2 and H_2O.

2. Boundary Dam Mine, Manalta Coal Ltd.,
Samples Manalta 1 & 2
Manalta 1: - 1.75 m from top of seam
Manalta 2: - 1 m from top of seam

3. Souris Valley Mine, Utility Coal Company
Samples Utility 1 - 3
Utility 1 - 1 m from top of seam
Utility 2 - 3.6 m from top of seam
Utility 3 - 0.39 m from top of seam

4. Klimax Mine, Manalta Coal Ltd.
Samples Klimax 1 & 2
Klimax 1: - 2.5 m from top of seam on downthrown side of fault
Klimax 2: - 1 m from top of seam on upthrown side of a fault, 1 km east of Klimax 1.

5. Bienfait Mine, Manalta Coal Ltd.
Samples Bienfait 1 & 2
Bienfait 1: - 1 m from top of seam
Bienfait 2: - 1.6 m from top of seam

Sample Collection and Preparation

All samples were put into double airtight polyethylene bags and sealed to prevent loss of moisture, and oxidation. Oxidation can lead to changes in the coal macerals.

The samples were individually air dried simply to remove excess moisture and then prepared using standard A.S.T.M. methods in the following way:

1. Crushed to -10 mesh, divided and crushed to -20 mesh
2. Mounted in Metset S.W. epoxy resin to form small blocks 1" in diameter. (Problems were encountered in finding a suitable resin).
3. Polished in the following manner:

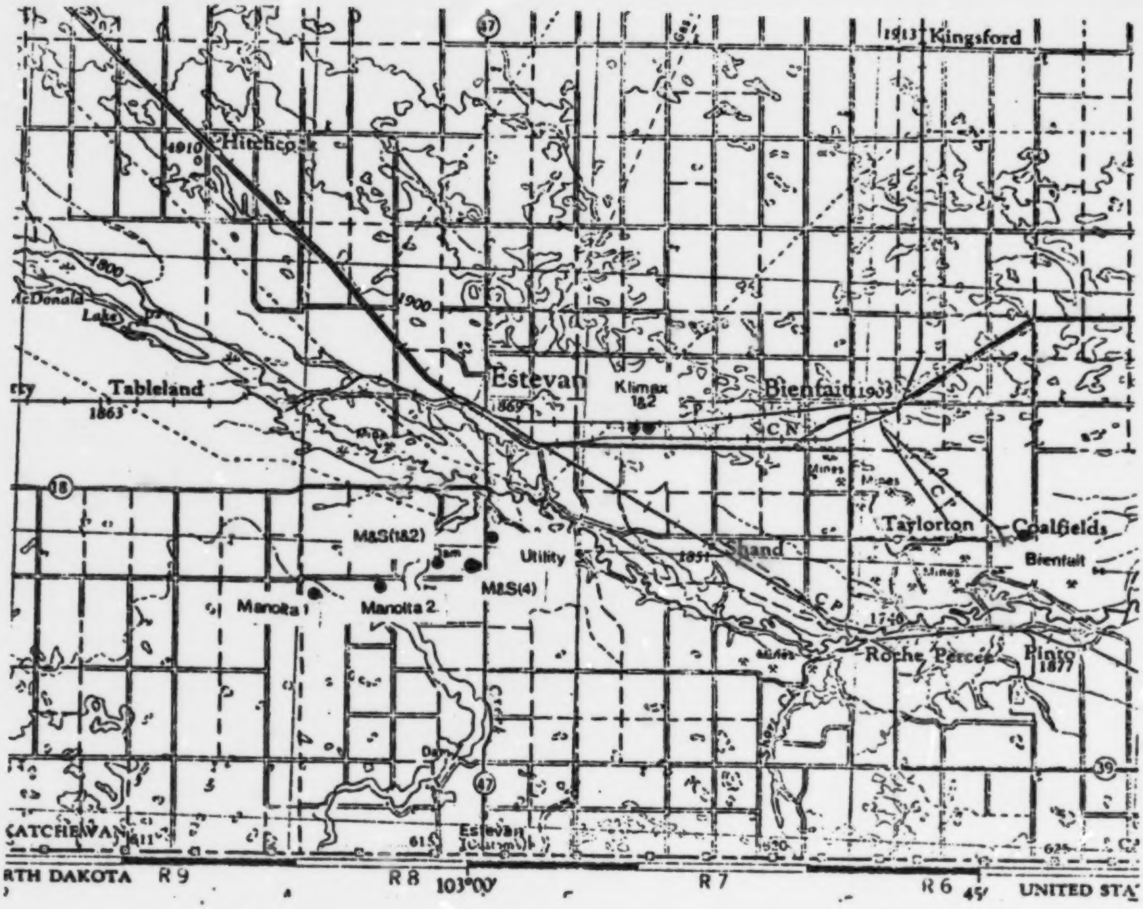
Kingsford
1913
Hitchcock
1910
1800
1900
McDonald Lake
Tableland
1863
Estevan
1869
Klimax 1&2
Bienfait
1903
CN
CP
Mines
Taylorton
Coalfields
Bienfait
M&S(1&2)
Utility
M&S(4)
Manolta 1
Manolta 2
Shand
1851
1740
Roche Percee
Pinto
1877
Estevan
18
47
39
CATCHEWAN
NORTH DAKOTA
R 9
R 8
103°00'
R 7
R 6
45'
UNITED STA

Figure 4: Estevan area showing the localities of mines from which samples were collected.

Scale: 1:250,000
1 inch = 4 miles

i. Ground on 240 silicon carbide

ii. Ground on 600 silicon carbide

iii. Polished on a rotating lap on 'selvyt' polishing cloths with

  a) 2μ grade alumina
  b) 0.3μ grade alumina
  c) 0.05μ grade alumina on silk cloth

iv. Washed with water to remove abrasives

4. Samples were stored in a dessicator to prevent the uptake of water which could cause the molds to crack and the polished surfaces to fracture.

Microscopy

The mounted polished blocks of coal were observed with: (1) A Leitz Ortholux reflecting light microscope system using oil immersion techniques to enhance the contrasts between the coal macerals. (2) A Leitz Dialux reflecting light microscope system adapted for fluorescence microscopy, using oil immersion.

The use of two types of microscope enhances the ability of the petrologist to identify the coal macerals. The Huminite and Inertinite macerals and the mineral matter content can be viewed adequately using white light but the Liptinite macerals, those richest in volatile hydrocarbon material, show very poor reflectance at the lignite coal rank. However liptinite macerals do fluoresce when illuminated with blue-violet light while the other macerals either do not or show very weak fluorescence. The weak fluorescence of structured huminites helps to distinguish it from unstructured huminite material.

Analytical methods - The individual coal macerals were identified on the basis of morphology, reflectance and fluorescence. When identification was complete a quantitative analysis was made using the point-count method. This standard method of analysis is documented in the I.C.C.P. Handbook of Coal Petrology. While this method often does not record minor amounts of some of the coal constituents, it gives a proportional analysis of the most abundant ones which is important from a technological viewpoint. For the purpose of this study a maceral count represents the volumetric proportions of the coal constituents most suited to gasification and therefore provides a suitable method for predicting the reactivity [5/] of the coal.

Diagnostic optical properties of individual macerals are recorded in Appendix I.

RESULTS AND DISCUSSION

Estevan Lignites

Representation of the maceral compositions of thirteen lignite samples from the Estevan area are shown diagramatically in Figures 5, 6, 7. Each maceral group (huminite, inertinite, liptinite) is represented by symbols, the proportion of mineral matter being represented also. Analyses by individual macerals and by maceral groups is given in Appendix II.

Huminite - The Estevan coal samples contain 60% or more of huminite macerals dividided on the basis of structure into unstructured, groundmass, and structured huminite. The unstructured materials comprise the completely

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[5/] Reactivity in this case is the ease with which the constituents lose volatile matter from the molecular structure, so increasing the carbon content, a change which is accompanied by an increase in reflectance of the coal.

gelified macerals - levigelinite, porigelinite and corpohuminite (see Table 1; Plate 1) - and probably have a low gaseous hydrocarbon yield on gasification. The groundmass material comprises detrital, partially gelified densinite (Plates 1, 2) which forms a matrix for other materials, eg. structured huminite, liptinite and inert macerals as well as mineral matter; the hydrocarbon yield is probably greater than that of unstructured huminite. The structured materials comprise texto-ulminite and eu-ulminite (Plates 3, 4) which are partially to wholly gelified tissues in which cell structure is retained. The structured group will produce most of the gaseous hydrocarbons obtained from huminite on gasification.

In Appendix II it can be seen that the dominant unstructured materials are corpohuminite and levigelinite. The groundmass huminites are almost all of gelinite type and the structured material is dominantly eu-ulminite (Plates 5, 6), highly gelified with small proportions of texto-ulminite.

Liptinite - The proportion of liptinite macerals is relatively high in samples from the Utility, Klimax and Bienfait mines, moderate in M & S 1 & 2 and Manalta 1 and 2, and very low in M & S 3 & 4. A high percentage of liptinite coincides with a high percentage of densinite in the coal in this case, which is to be expected since liptinite macerals are finely dispersed throughout groundmass material as individual bodies (Plate 7). In most of the Estevan coals the liptodetrinite maceral is the most abundant and this yields about 100% volatile matter when heated and 50% hydrogen.

Inertinite - Except for sample M & S 2, all the Estevan samples contain relatively moderate to low amounts of inertinite macerals. These macerals are unreactive and usually concentrate in the fly ash when the lignite is heated; they do in fact hinder complete reaction of the

Figure 5

Petrographic composition of Estevan lignites

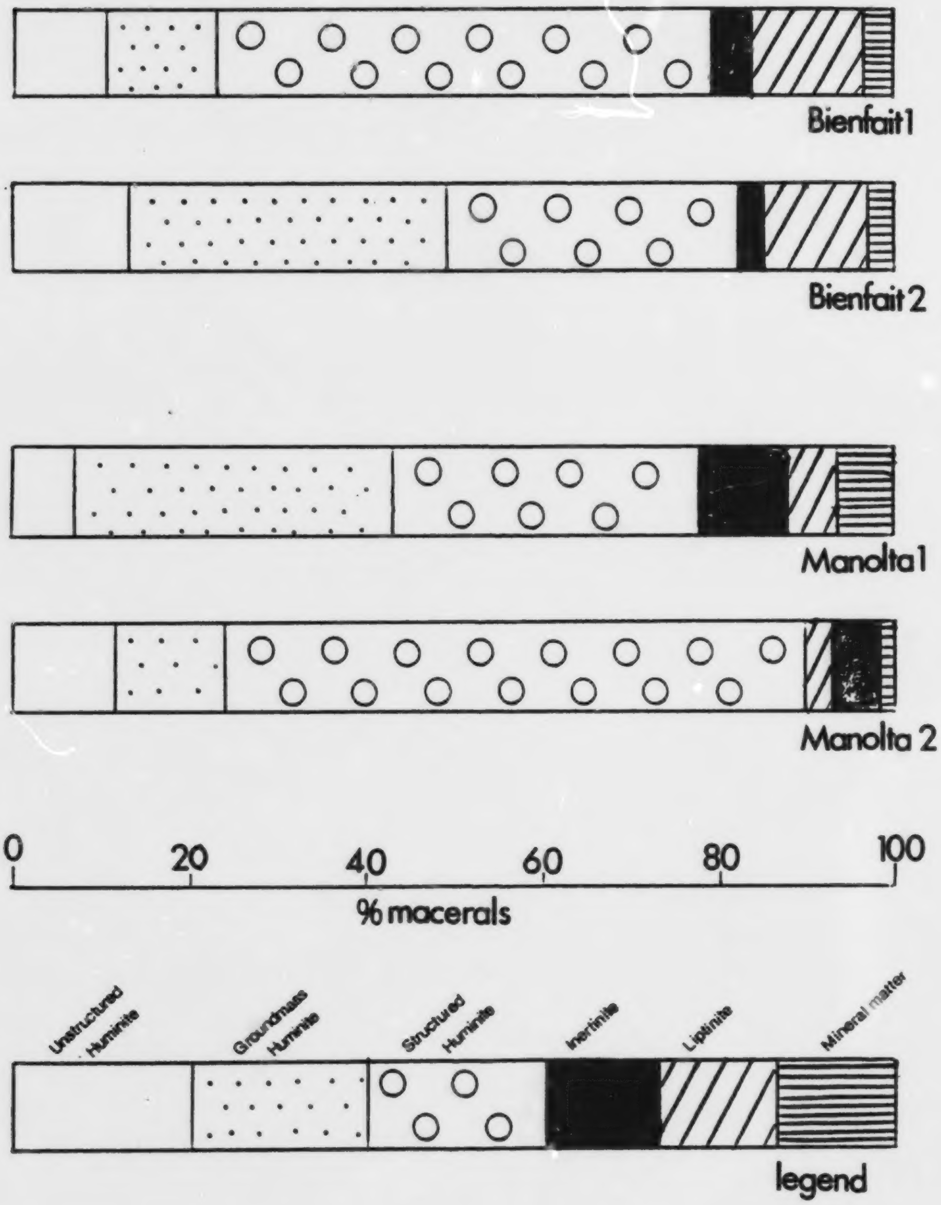


Figure 6

Petrographic composition of Estevan lignites

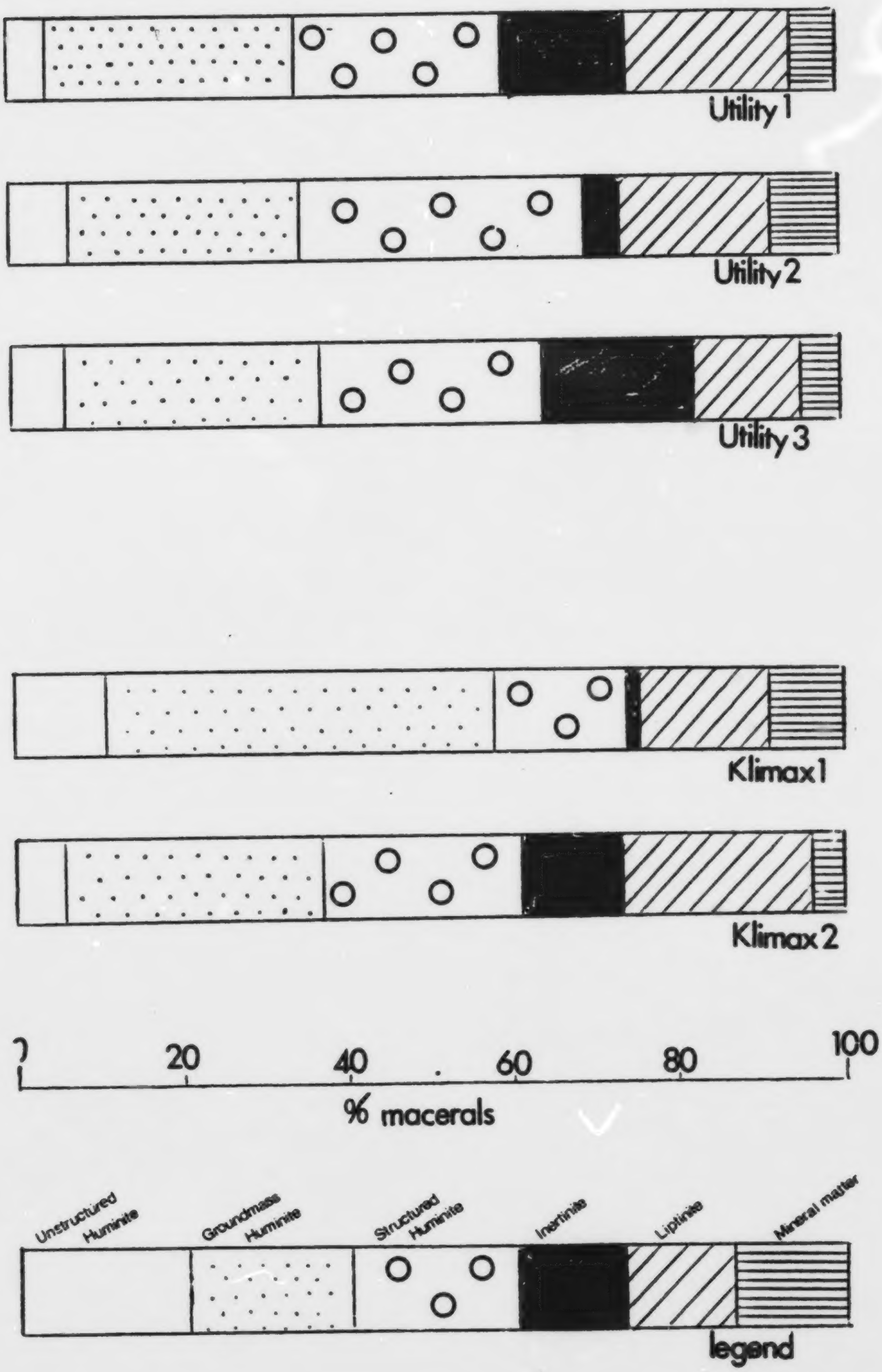
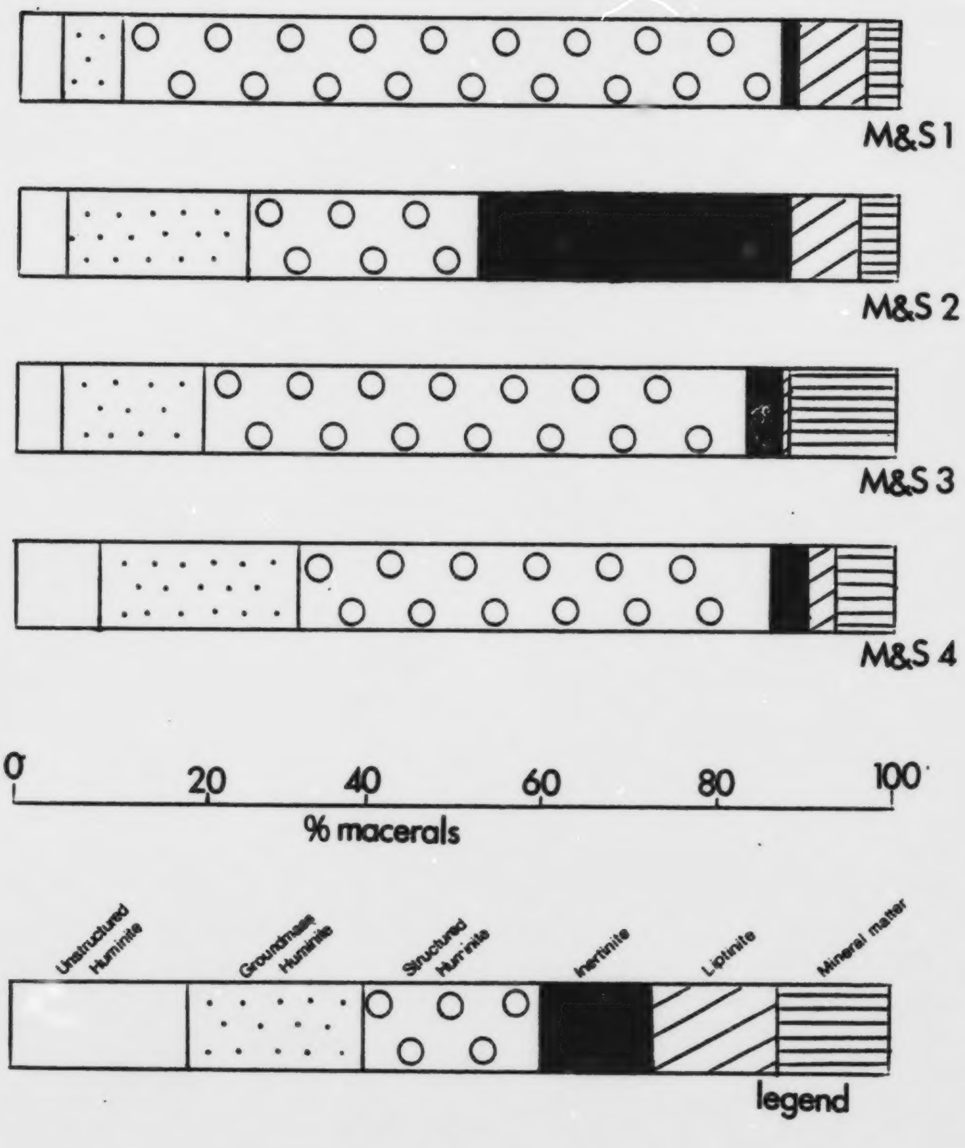


Figure 7

Petrographic composition of Estevan lignites



coal. The presence of inertodetrinite within the densinite groundmass material could hinder complete reaction of the densinite component.

Mineral Matter - The mineral matter content is quite low in most of the Estevan samples and comprises mainly siliceous material and clay minerals. The coals are poor in pyrite, productive of sulphurous gases on heating; pyrite occurs mainly as discreet entities which can be separated from the coal; that which is present as finely divided pyrite embedded in the groundmass material and associated with inerts is difficult to remove and thus can cause problems on heating. The mineral matter is concentrated in the fly ash after reaction has taken place and where a large percentage is present in a coal it may hinder complete reaction on gasification.

Comment - The maceral composition of all lignite and bituminous coals depends upon the position of the sample within the seam. In the Estevan coals there is great variation in maceral composition vertically and laterally throughout the seam.

Shaunavon Lignites

Graphical representation of the proportions of the maceral groups in Shaunavon lignites is shown in Figures 8 & 9 while the individual maceral analyses are recorded in Appendix III. The Shaunavon coals contain similar maceral groups to the Estevan coals but differ in individual maceral content and in the morphology of the macerals, particularly the structured ones.

Huminite - The unstructured portion of the huminite group is much lower than in the Estevan lignite being composed mainly of the corpohuminite type, as discreet bodies associated with structured material rather than totally gelified tissues of levi-or porigelinite. Groundmass huminite forms the dominant maceral as aggregated, detrital, gelified cells & tissues containing varying proportions of liptinite, inert material and mineral matter. The structured material is, except in a few cases, dominantly eu-ulminite and of a different nature to that found in the Estevan coals. It comprises compacted cell tissues of much smaller size and is more gelified and possibly therefore less reactive.

Liptinite - The liptinite content is moderate to high in most of the Shaunavon samples, particularly in No. 72. It comprises dominantly liptodetrinite which is the most reactive of the Liptinite group.

Inertinite - The inert content is dominantly fusinite, associated with groundmass huminite which could hinder the reactivity of the huminite. Proportionally it is high to moderate and consists dominantly of siliceous material & clay minerals.

Chars and Sinters

Chars - Three samples of Utility No. 1 sample (Estevan) were gasified under different conditions. The chars were crushed, mounted and polished in the same manner as the coals and viewed under the reflecting light microscope using white light illumination.

Sample No:	Conditions of Gasification
Char No. 9	Coal & steam in nitrogen atmosphere
Char No. 10	Coal & steam & air
Char No. 11	Coal & air

Degree of reflectance in white light is a diagnostic property of brown coal macerals (Appendix I). Upon heating the reflectance increases as a result of the artificial increase in coal rank. Reactivity of individual macerals under different sets of gasification conditions can be assessed in the same way. It was possible in this study to determine under which set

Figure 8

Petrographic composition of Shaunavon lignites

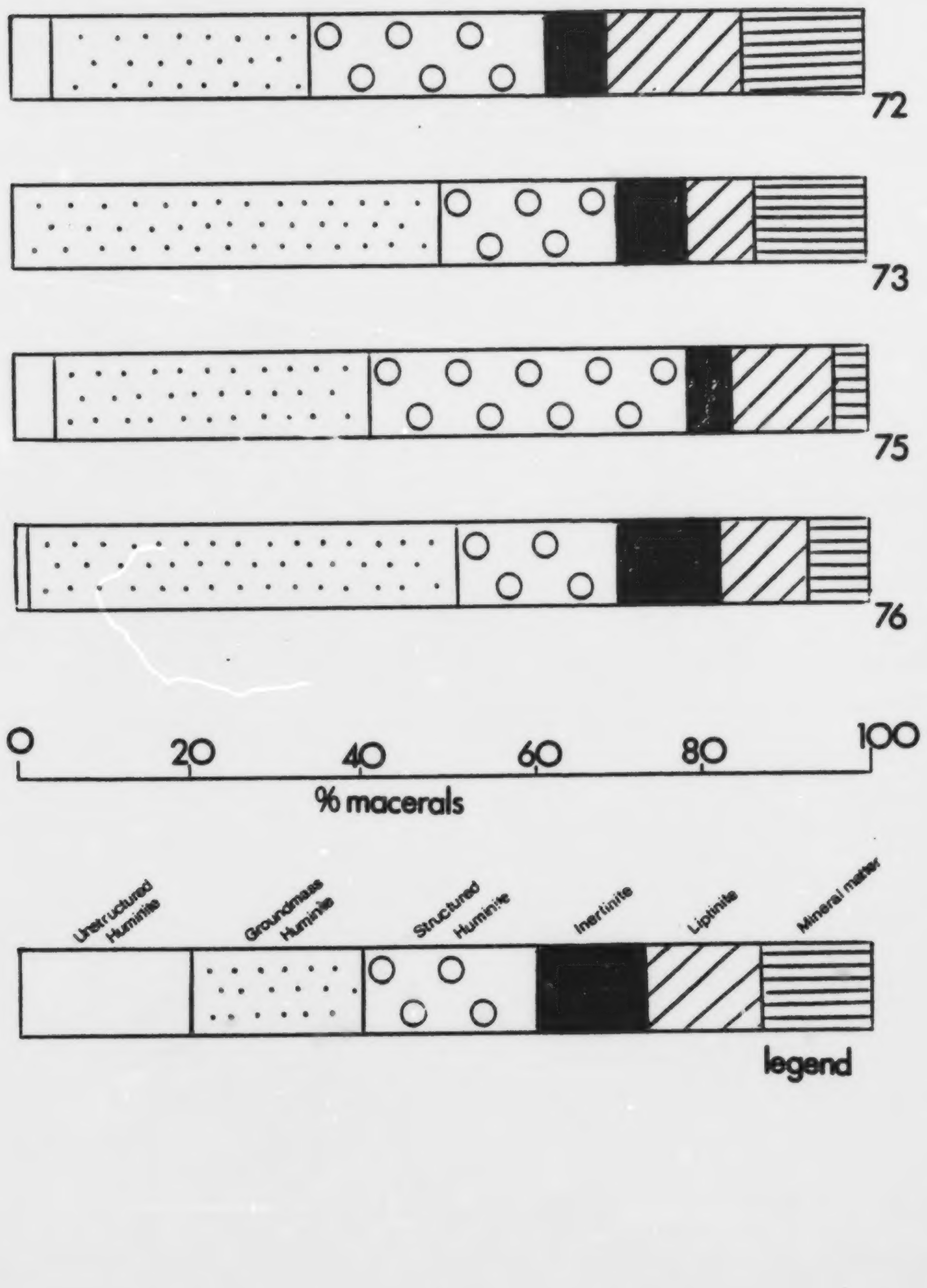
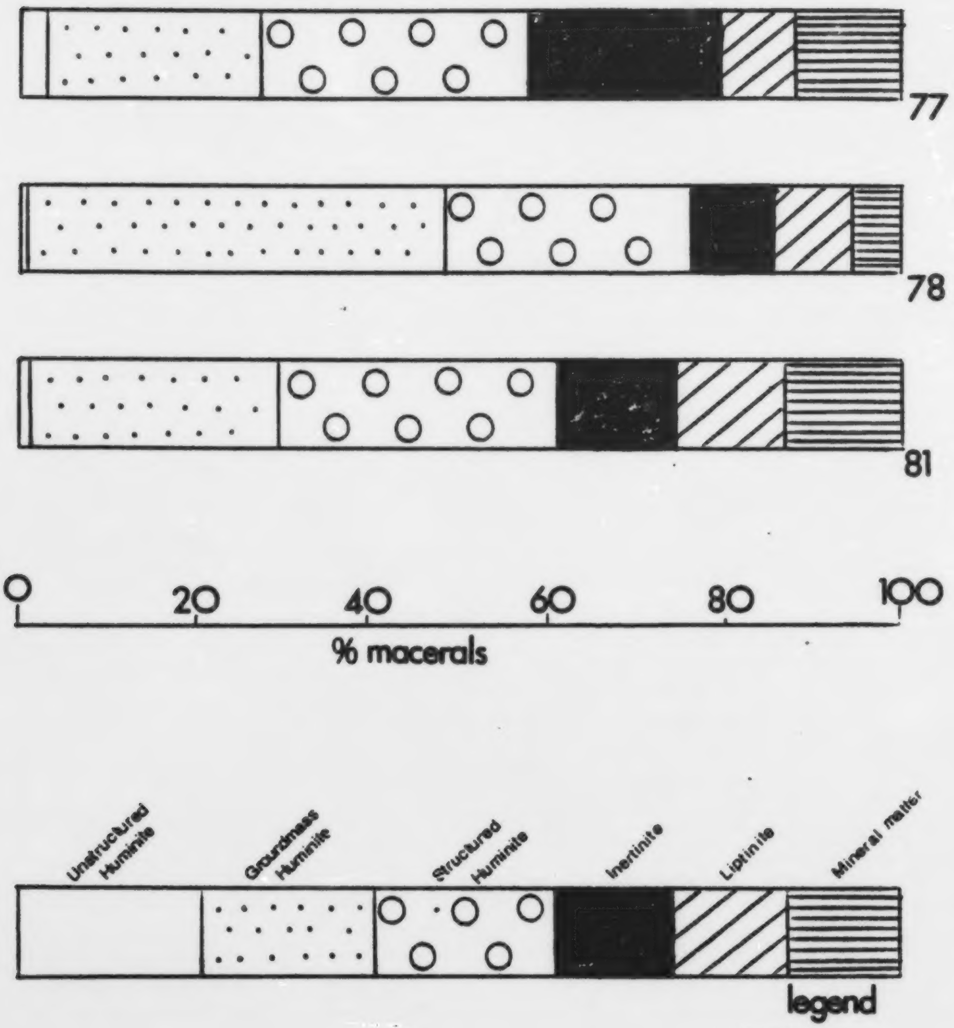


Figure 9

Petrographic composition of Shaunavon lignites



of conditions the coal had reacted most completely and which macerals had reacted most fully by assessing the reflectance, particularly that of huminite and liptinite. No granular mosaic texture, indicative of coke, was detected in any reacted coal in the char samples:

Char Sample No. 9 (coal & steam in nitrogen)

The structured huminites reacted completely appearing homogenous and highly reflecting (reflectance equivalent to that of fusinite - Appendix I) They contain a large number of gas bubble holes as a result of loss of volatile constituents (Plates 9, 10, 11, 12). The unstructured corpohuminite also reacted completely (Plate 13) and the very low reflecting liptinites increased in reflectance to equal that of fusinite. The inert materials did not change. The densinite or groundmass huminite did not show as great an increase in reflectance as the structured material (Plate 14) and hence did not react as completely. Mineral matter occurs as silica.

Char No. 10 (coal & steam & air)

The appearance of the char was similar to that of No. 9 indicating that the liptinite, corpohuminite and eu-ulminite had reacted completely but large quantities of unreacted coal were present in the form of densinite.

Char No. 11 (coal & air)

The high reflectance of all the macerals including the densinite portion indicated that all had reacted, hence coal and air in a helium atmosphere appears to have been the most reactive.

Coal sinters - The sinters of samples 10 and 11 comprised dominantly fused siliceous material, unreacted coal and reacted structured material in the form of angular fragments scattered throughout unburnt coal. The proportion of unreacted material was less in sample No. 11. which was gasified in air.

CONCLUSION

This limited petrological study of lignite coals was valuable in initial assessment of gasification potential. Additional petrological work on fresh coals and on chars from various sources is necessary to establish a direct correlation between maceral composition and gasification potential.

The microscopical observations have shown that after gasification the structured huminite and liptinite macerals reacted most completely. The reactions of the groundmass and unstructured huminites depended upon the conditions under which gasification was carried out. The inert macerals did not react.

The author feels that a petrological assessment of the gasification potential of the lignite lies therefore in the assessment of the ratio:

structured huminite + liptinite: unstructured + inert macerals

Examination of chars and sinters gave a fairly good indication of those constituents which react most readily during gasification tests and showed that less unreacted coal is present in chars resulting from coals gasified in air. There was no indication of coke formation (granular mosaic texture) during the gasification tests.

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APPENDIX I

PETROLOGICAL DESCRIPTIONS OF MACERALS

(Based on recommendations of I.C.C.P.)

Huminites

A) Structured

a) Textinite - Huminitic cell wall material in brown coals comprising plant cell walls of isolated individual cells and cell tissues which are ungelified. The cell lumens are mainly open but tissues may be deformed or torn.

Reflectance - Low, appears dark grey.

Fluorescence - Weak; part fluorescene in brown tones cellulose bearing textinite fluoresces very strongly.

Chemical Constitution - Humic substances and remains of lignin and cellulose

Practical importance - ash content low
tar content high
gas yield high on carbonisation

b) Ulminite - Completely gelified plant material & plant cell walls; cell lumens are partly or wholly closed and cells are often packed together.

Reflectance - Weak but higher than that of textinite appearing dark to mid grey.

Fluorescence - None or very weak dark brown fluorescence.

Chemical Constitution - Humic acid progenitor with humates & traces of lignin and cellulose.

Practical importance - little tar yield
gas yield less than textinite

B) Groundmass

a) Attrinite - Ungelified humic groundmass of brown coal comprising detrital material, eg. cell wall fragments and porous huminitic material, spongy habit.

Reflectance - Dark grey

Fluorescence - None or weak, dark brown fluorescence

Chemical constitution - Humic substance with some lignin and cellulose

Practical importance - low tar yield
gas yield moderate-high

b) Densinite - Gelified, less compressed humic groundmass of brown coals, of detrital particles including cell-wall debris and formless dense homogeneous huminite material. Forms a matrix for other brown coal macerals.

Reflectance - Medium grey

Fluorescence - None or weak dark brown fluorescence

Chemical Constitution - Humic materials and lignin remains.

Practical importance - Gas and Tar yields depend upon macerals present in the groundmass. If associated with Inertinite - low. If associated with Liptinite - high.

C) Unstructured

a) Corpohuminite - Isolated phlobaphinitic cell excretions and huminite cell infillings. Seen as discrete rounded bodies with smooth surfaces.

Reflectance - Medium to light grey

Fluorescence - None

Practical importance - Produces pyrocatechin and acid oils on carbonisation.

b) Gelinite - Precipitated humic gels without any definite form, homogeneous huminite material.

(i) porigelinite - Porous to granular

(ii) levigelinite - Structureless, homogeneous with striated appearance.

Reflectance - Bright to medium grey

Fluorescence - None to very weak

Chemical constitution - Humic acids

Practical importance - Reduces mechanical strength of coal, low gas yield

D) Inertinite

a) Sclerotinite - Oval bodies of high reflectance derived from fungal remains, either tubular or displaying chambers.

Reflectance - Light grey to white

Fluorescence - None

b) Inertodetrinite - A collective term for detrital inertinite particles of small size which cannot be attributed to the other macerals of inertinite group (semifusinite, fusinite, macrinite, sclerotinite). Particles are splintery or angular.

Reflectance - Light grey to white

Fluorescence - None

Chemical constitution - low hydrogen content
low volatile matter

c) Semifusinite - Lignite cells whose reflecting capacity lies between weakly reflecting huminites and strongly reflecting fusinite. Formed of tissues with more or less well preserved cell structure.

Reflectance - Stronger than huminites, less than fusinite, grey-white

Fluorescence - None

d) Fusinite - Highly reflective cell walls exhibiting 'Bogenstructure' cell lumens occasionally filled with gelinite or mineral matter, eg. clay minerals or pyrite.

Reflectance - Strong - white

Fluorescence - None

e) Macrinite - Dense structure with reflectance equivalent to fusinite, often forming a groundmass for other macerals.

Reflectance - Strong - white

Fluorescence - None

Inertinite macerals are essentially "fossil charcoal" and consequently have high carbon content and low hydrogen and volatile matter yields. These macerals retard gasification and concentrate in the ash.

E) Liptinites

a) Alginite - Often displays the original structure of algal colonies as tubular or oval bodies of small size.

Reflectance - Dark brown to black

Fluorescence - Strong, yellow to white to green

Chemical constitution - Esters of glycerol and higher saturated fatty acids and unsaturated oleic acids. Porphyrins.

Practical importance - rich in volatile matter
rich in hydrogen

b) Liptodetrinite - A collective term for liptinitic constituents which are finely detrital particles and which cannot be identified as other liptinite macerals eg. cutinite, sporinite, alginite, resinite.

Reflectance - Black to dark grey

Fluorescence - Strong, greenish yellow to citron yellow

Chemical importance - Content depends upon origin, usually hydrogen rich, usually volatile matter rich, hydrogenation potential excellent.

c) Cutinite - One-sided serrated bands of plant cuticles

Reflectance - Black to dark grey

Fluorescence - Strong, greenish, yellow-orange

Chemical constitution - Very high hydrogen content (75% of the molecule)

Practical importance - Volatile matter yield high
Hydrogen yield high

d) Resinite - Cell excretions and in-situ infillings occurring as discrete bodies, oval or rod shaped.

Reflectance - Black to dark grey

Fluorescence - Strong, yellow-orange-light brown

Chemical constitution - Hydrogen high

Practical importance - Volatile matter yield 76-100%

Hydrogen yield high

e) Sporinite - Spore exines and perines - often retains the shape of the original spore coverings with a spindle-shaped central hollow, flattened along the bedding planes of the coal.

Reflectance - Dark brown

Fluorescence - White to yellowish - orange

Chemical constitution - Contains much sulphur

Practical importance - 22% volatile matter yield

The liptinite macerals release an abundance of gaseous hydrocarbons when heated and a coal rich (20%) in such constituents will yield the greatest amounts of potential S.N.G. However the volumetric proportions of liptinite in coal is relatively low except in cannel and boghead coals.

APPENDIX II

MACERAL ANALYSES OF ESTEVAN COALS

	Maceral %	Utility 1	Utility 2	Utility 3	Klimax 1	Klimax 2
HUMINITE	Levigelinite		1	1	2	2
	Porigelinite	3	4	5	8	1
	Corpohuminite	2	2	0.5	3	3
	Textinite					
	Texto-Ulminite	2	0.5	2.5	3	1
	Eu-Ulminite	23	34	24.5	13	23
	Densinite	30	28	31	47	31
	Attrinite					
INERTINITE	Inertodetrinite	5		2.5	0.5	1
	Semifusinite	1	1	12		2
	Fusinite	6.5	2	2.5	0.5	6
	Semimacrinite	1				3
	Macrinite	2.5	1	1	0.5	3
	Sclerotinite					
LIPTINITE	Sporinite	5	8	4	6	8
	Cutinite	1	4	3	1	6
	Resinite	5	3	2	2	3
	Liptodetrinite	5	2	3	2	6
	Alginite				1	
	Suberinite	3	1	1.5	2	
	Mineral Matter	5	8.5	4.5	7.3	3
	Total %	100	100	100	100	100

MACERAL ANALYSES OF ESTEVAN COALS (cont'd)

	Maceral %	M&S 1	M&S 2	M&S 3	M&S 4
HUMINITE	Levigelinite	0.5	1	1	1.5
	Porigelinite	4	2	1.5	5
	Corpohuminite	0.5	2	2	3
	Textinite				
	Texto-Ulminite	9.5	1	4.5	2
	Eu-Ulminite	66	25	57.5	52
	Densinite	6.7	21	16	22.5
	Attrinite				
INERTINITE	Inertodetrinite		25	0.5	0.5
	Semifusinite				2.5
	Fusinite		8.7	0.5	0.5
	Semimacrinite	1	2		
	Macrinite	1			
	Sclerotinite				
LIPTINITE	Sporinite	2	2	1.5	1.5
	Cutinite		1	0.5	
	Resinite		1	0.5	
	Liptodetrinite	1	2	0.5	0.5
	Alginite				
	Suberinite	5	1.5	0.5	0.5
	Mineral Matter	3	5	12.5	6
	Total %	100	100	100	100

MACERAL ANALYSES OF ESTEVAN COALS (cont'd)

	Maceral %	Bienfait 1	Bienfait 2	Manolta 1	Manolta 2
HUMINITE	Levigelinite	3.2	3.5	2.5	3.5
	Porigelinite	2.6	5.5	1	6.2
	Corpohuminite	2	5	3.5	1.7
	Textinite				
	Texto-Ulminite	6	2	3.5	16
	Eu-Ulminite	50	31	32	50
	Densinite	12.5	33.5	36	12.5
	Attrinite				
INERTINITE	Inertodetrinite	2	0.5	2	0.7
	Semifusinite		1	2	0.7
	Fusinite	1	1	5	1.7
	Semimacrinite	0.5		0.5	
	Macrinite	1	0.5	1	1.3
	Sclerotinite	0.5			0.7
LIPTINITE	Sporinite	4.5	3	4	2
	Cutinite	4	6	0.5	2
	Resinite	1	2	0	2
	Liptodetrinite	6	4	1	
	Alginite				
	Suberinite	1	2		
	Mineral Matter	0	0.5	6	2
	Total %	100	100	100	100

MACERAL ANALYSES OF ESTEVAN COALS (cont'd)

Group Analysis

Maceral Group %	Utility 1	Utility 2	Utility 3	Klimax 1	Klimax 2
Huminite (Structured)	25	34.5	27	16	24
(Groundmass)	30	28	31	47	31
(Unstructured)	5	7	6.5	11	6
Liptinite	20	18	13.5	14	23
Inertinite	15	4	18	1.5	12
Mineral Matter	5	8.5	4.5	7.5	3

Maceral Group %	M&S 1	M&S 2	M&S 3	M&S 4
Huminite (Structured)	75.5	26	62	54
(Groundmass)	6.7	21	16	22.5
(Unstructured)	5	5	4.5	9.5
Liptinite	8	7.5	1	2.5
Inertinite	2	35.7	3.5	3.5
Mineral Matter	3	5	12.5	6

Maceral Group %	Bienfait 1	Bienfait 2	Manalta 1	Manalta 2
Huminite (Structured)	56	33	35.5	66
(Groundmass)	12.5	36	36	12.5
(Unstructured)	10.8	13	7	11.4
Liptinite	17	17	5.5	6
Inertinite	4.5	3	10	3.5
Mineral Matter	2	0.5	6	2

APPENDIX III

MACERAL ANALYSES OF SHAUNAVON COALS

	Maceral %	72	73	75	76	77	78	81
HUMINITE	Levigelinite							
	Porigelinite							
	Corpohuminite	5		5	1.5	3	1	13
	Textinite							
	Texto-Ulminite			1			1.5	
	Eu-Ulminite	28	21	36	19	30	28	32
	Densinite	30	50	37	50	24	47	28
	Attrinite							0.5
INERTINITE	Inertodetrinite	2	4	4	6	11	4	5.5
	Semifusinite	4	1	1	4	4	2.3	2
	Fusinite	1	3		2	5	3	4
	Semimacrinite							1.3
	Macrinite					2		0.5
	Sclerotinite							
LIPTINITE	Sporinite	7	4	5	3	4	3	3
	Cutinite	1		1	1			3
	Resinite		1	1	1	1	2	1
	Liptodetrinite	8	3	5	4	4	3	3
	Suberinite				1			1
	Alginite							1
	Mineral Matter	14	13	3	7.5	12	5.3	13

MACERAL ANALYSES OF SHAUNAVON COALS (cont'd)

Group Analysis

MACERAL GROUP %	72	73	75	76	77	78	81
Huminite (Unstructured)	5		5	1.5	3	1	1.3
(Groundmass)	30	50	37	50	24	47	28
(Structured)	28	21	37	19	30	28	32
Liptinite	16	8	12	10	9	8	12
Inertinite	7	8	5	12	22	9.3	13.3
Mineral Matter	14	13	3	7.5	12	5.3	13

APPENDIX IV

CONSULTATION WITH LEADING WORKERS IN THE FIELD OF LIGNITE PETROLOGY

1. Consultation with Dr. B.N. Nandi, CanMet, Bells Corner, Ottawa,
May 28 & 29, 1978

The nature of fly ash and coal carbonisation chars was discussed in terms of the proportions of unburnt coal, oxidised huminite and siliceous sinter. Recent work by Nandi et al (1977) shows that in Western Canadian coal there can be as much as 18% ash which may include oxidised huminite, unburnt coal and inert macerals.

In relation to fresh lignite coal petrology the possibility of confusion arising over the recognition of liptinite macerals and mineral matter when coal is viewed under fluorescent light was also considered. It was decided that this can be avoided by a) studying the habit and form of the fluorescing materials and by b) the use of microscopical system incorporating interchangeable light sources and filter systems to accommodate both white and fluorescent light.

Lignite petrology is currently being carried out by Dr. M. Mackowsky, W. German, whose work on Canadian Hat Creek lignites concerning maceral identification (unpublished) was also discussed.

2. Paper given by Dr. D. Marchioni, Institute of Sedimentary and Petroleum Geology. Geol. Surv. Canada. Calgary at VIII meeting of the Canadian Coal Petrographers Group in Ottawa, May, 1978

Dr. Marchoini illustrated the increase in huminite reflectance of lignites from Hat Creek, Alberta, depicting the usual pattern of rank increase with depth that is found in reflectance studies on bituminous coal. He pointed out however that while there is a possibility of reflectance being used as a rank parameter in lignite coals, there is at present no good correlation with other rank parameters such as volatile matter and calorific value as exists at bituminous coal rank.

3. Consultation with Dr. F.C. Ting, University of W. Virginia, Morgantown, West Virginia, 7-10th June 1978

Previous work by Dr. Ting on lignites from North Dakota showed them to be similar in composition to the lignites of Southern Saskatchewan. The geobotanical approach adopted by Dr. Ting in his study of thin sections of North Dakota lignites facilitated recognition of coal macerals, their origins and chemistry which are important to applied coal petrology. An understanding of primary and secondary root and bark tissues shown in thin sections, aids in recognition of primary structured macerals - textinite and texto-ulminite- as distinct from attrinite and densinite groundmass huminites. Discussions on brown coal nomenclature were facilitated by the use of a television screen linked to the reflected light microscope system and by photographic slides of the lignite described.

4. Consultation with Dr. A.C. Cameron, Institute of Sedimentary & Petroleum Geology. Geol. Survey Canada, Calgary

Dr. Cameron was one of the first workers to attempt a petrological study of lignites from Saskatchewan making petrographic and chemical analyses of Estevan coal. The problems of definition of lignite macerals and the application of the nomenclature of the I.C.C.P. to Canadian Coals was the main object of discussion. It was decided that Densinite, while being a distinct huminite maceral, could in fact be more aptly recognised in terms of a microlitho type, i.e. maceral associations, since it is associated with detrital material, inerts and liptinite as well as huminite macerals. Some difficulty in adequately defining densinite as opposed to eu-ulminite of a certain type had previously been experienced. It was also apparent that the I.C.C.P. nomenclature system did not suitably cover the description of texto-ulminite and ulminite when applied to Saskatchewan coals.

5. Consultation with Dr. D. Marchioni, Institute of Sedimentary and Petroleum Geology, Geological Survey Canada, Calgary, Alberta

Similar discussions with Dr. Marchioni took place in which the nature of Saskatchewan lignites and Hat Creek lignites from British Columbia were compared which greatly benefited the petrological study of Saskatchewan coal.

APPENDIX V

SUBSIDIARY EXAMINATION OF UTILITY 2, RUN 19 SEPTEMBER, 1978

Analysis of: a) injected coal

b) discarded fines

c) coal ash

d) coal sinter

a) Injected coal

Petrographic analysis showed that:

1. Unstructured (less reactive) huminite and structured (fairly reactive) huminites were concentrated into that portion of the coal which was gasified.
2. That this portion of the coal was depleted in silica, liptinite and densinite.

Comments - The removal of silica is advantageous in that its presence hinders the reactivity of the coal but a) the removal of densinite and b) even more important, the removal of liptinite (hydrogen rich) is disadvantageous as the injected coal is depleted to some degree in the high potential gas-producing constituents.

b) Fines - (discarded from injected coal)

This portion of the coal was found to contain a large percentage of densinite (20-30%), about 25-30% of the total liptinite in the coal , silica and inert material. A small proportion of the fines comprised unstructured and structured huminite.

Comments - As a result of discarding the finer portion of the lignite a large portion of hydrogen-rich liptinite components and densinite are removed from the injected coal which reacts quite well in air. Consequently unstructured huminite, which has a much lower hydrocarbon-producing potential than either the liptinites or the other huminite macerals, is concentrated in the injected coal.

The concentration of silica and inerts in the discarded portion is advantageous.

c) Ash

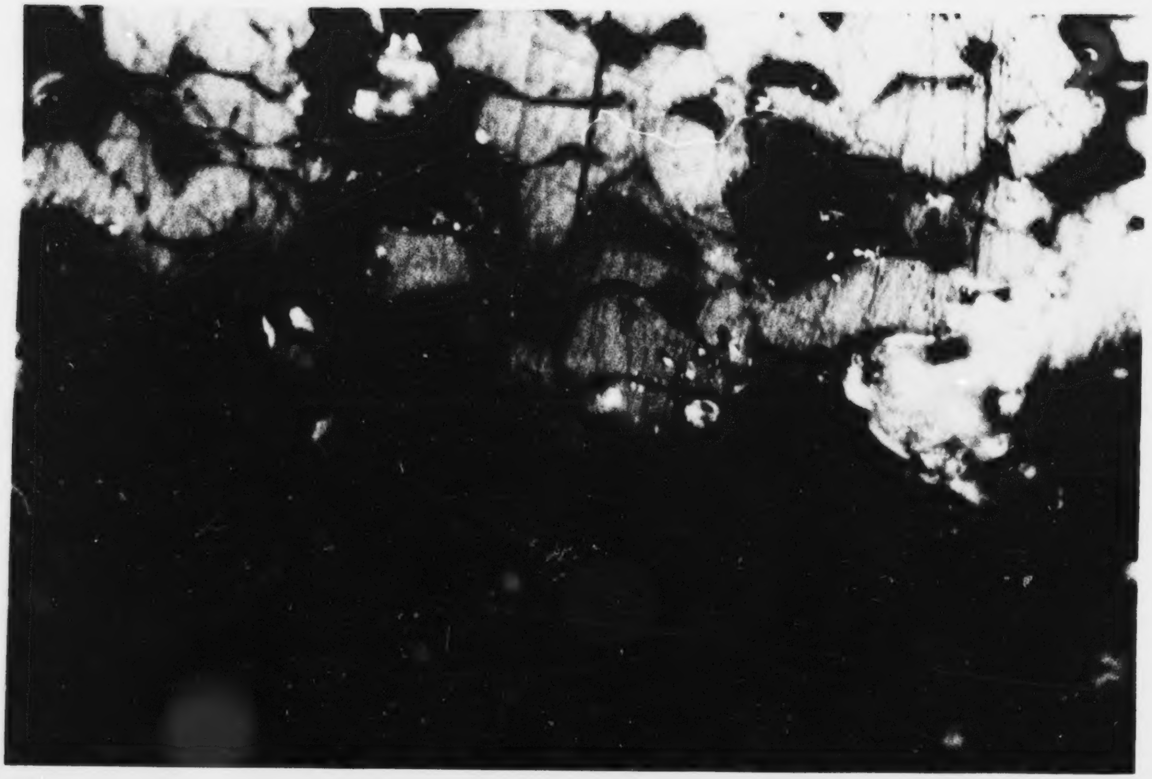
As previously recorded the ash was found to be comprised mostly of mineral matter - particularly silica and a small percentage of coal of which 85-90% had reacted and 10-15% had not, none of which exhibited the granular mosaic coke texture.

d) Sinter

The sinter was of a fused siliceous nature and contained angular splinters of unreacted coal trapped by mineral material (which therefore was prevented from reacting) and minute fragments of reacted coal. The presence of mineral matter therefore hinders the complete reaction of the coal.

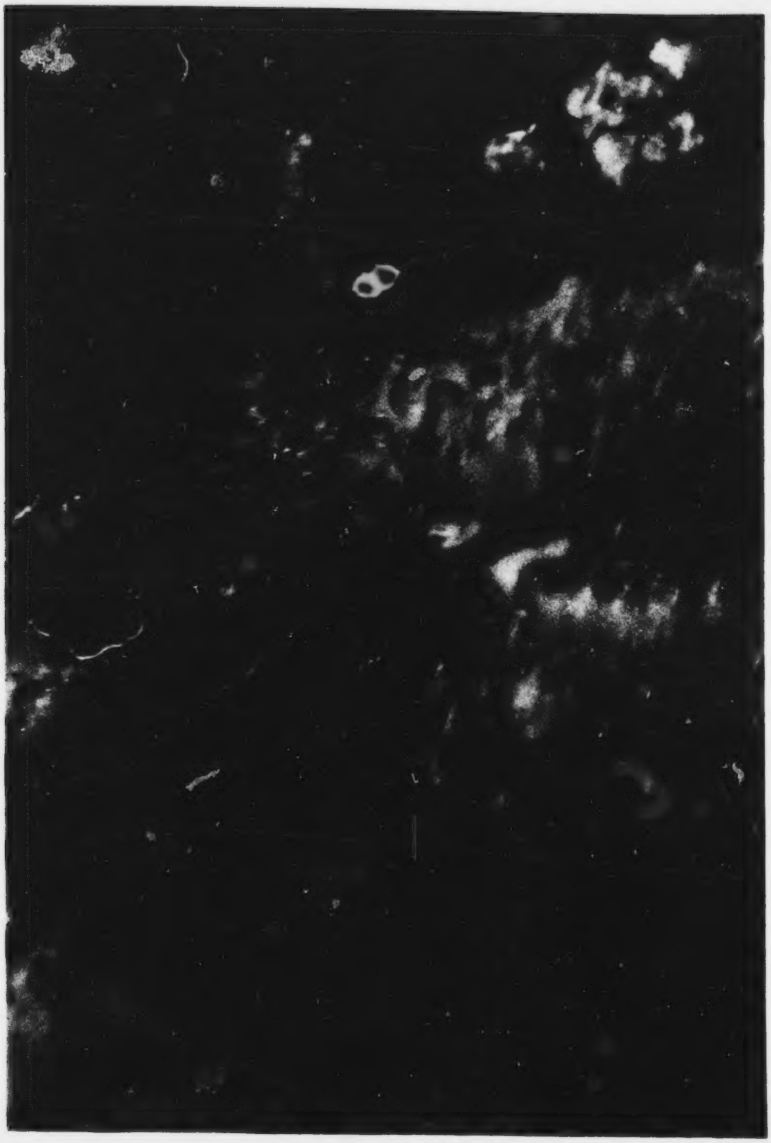
APPENDIX VI

PLATES

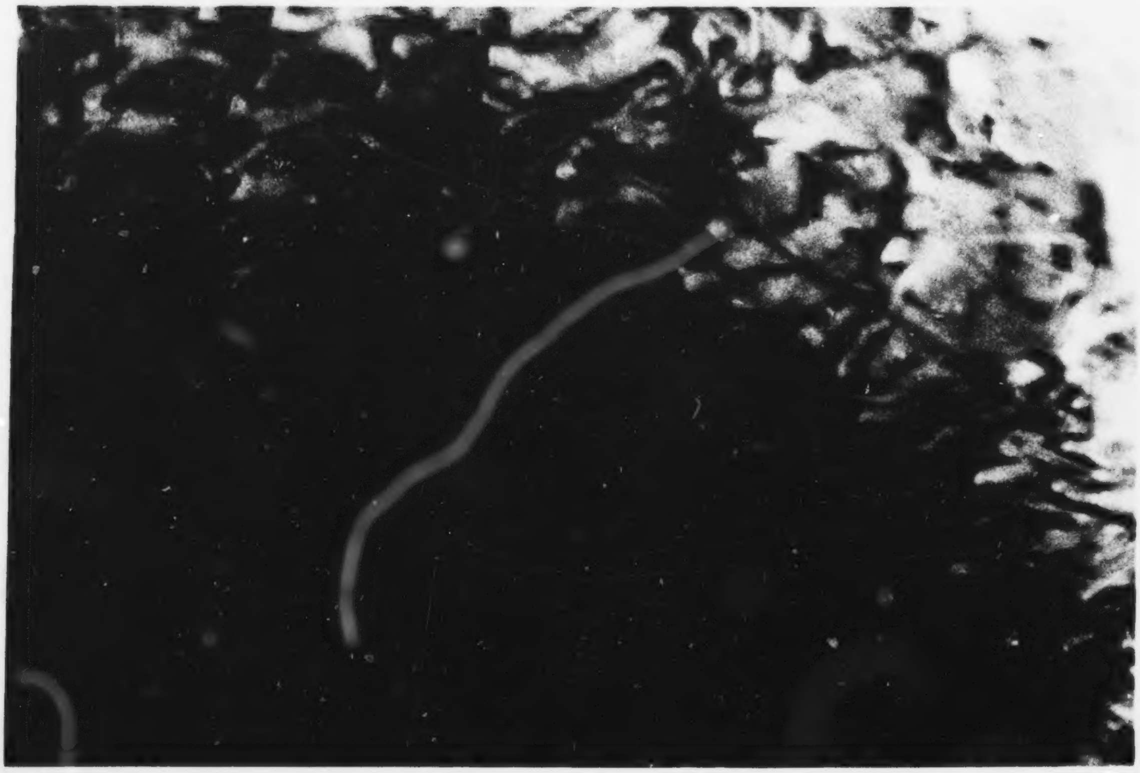


1. Unstructured huminite - Corpohuminite bodies (top) with Densinite (groundmass)

X480 Ordinary light Utility 2



2. Groundmass huminite - Densinite X480 Ordinary light Bienfait 2

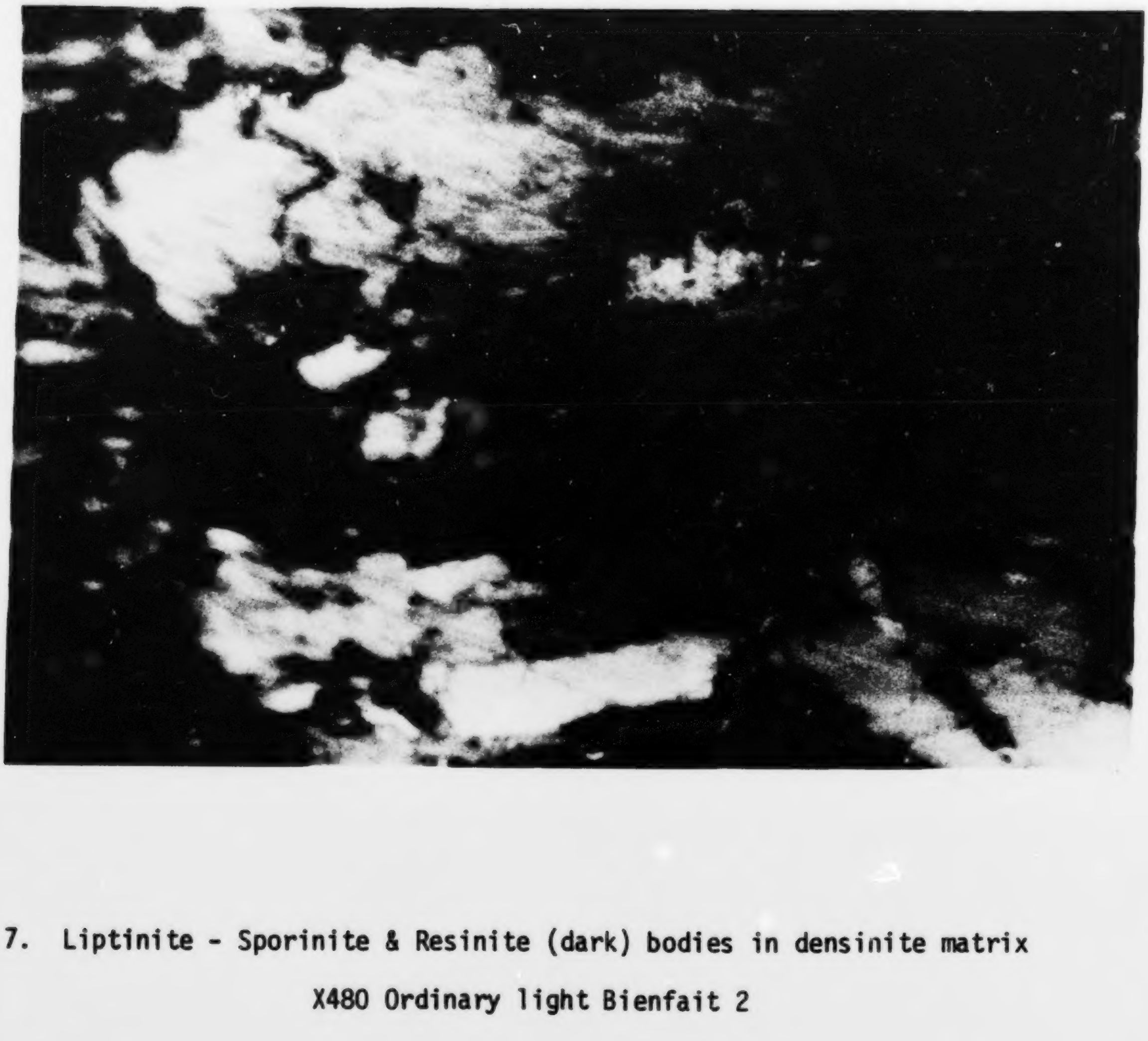


3. Structured huminite - Texto-ulminite (bottom left) grading to Eu-ulminite (top right) X480 Ordinary light M & S 1

4. Structured huminite - Texto-Ulminite X480 Ordinary light MMS 1

5. Structured huminite - Eu-ulminite X480 Ordinary light Manolta 1

6. Structured huminite - Eu-ulminite X480 Ordinary light Bienfait 2



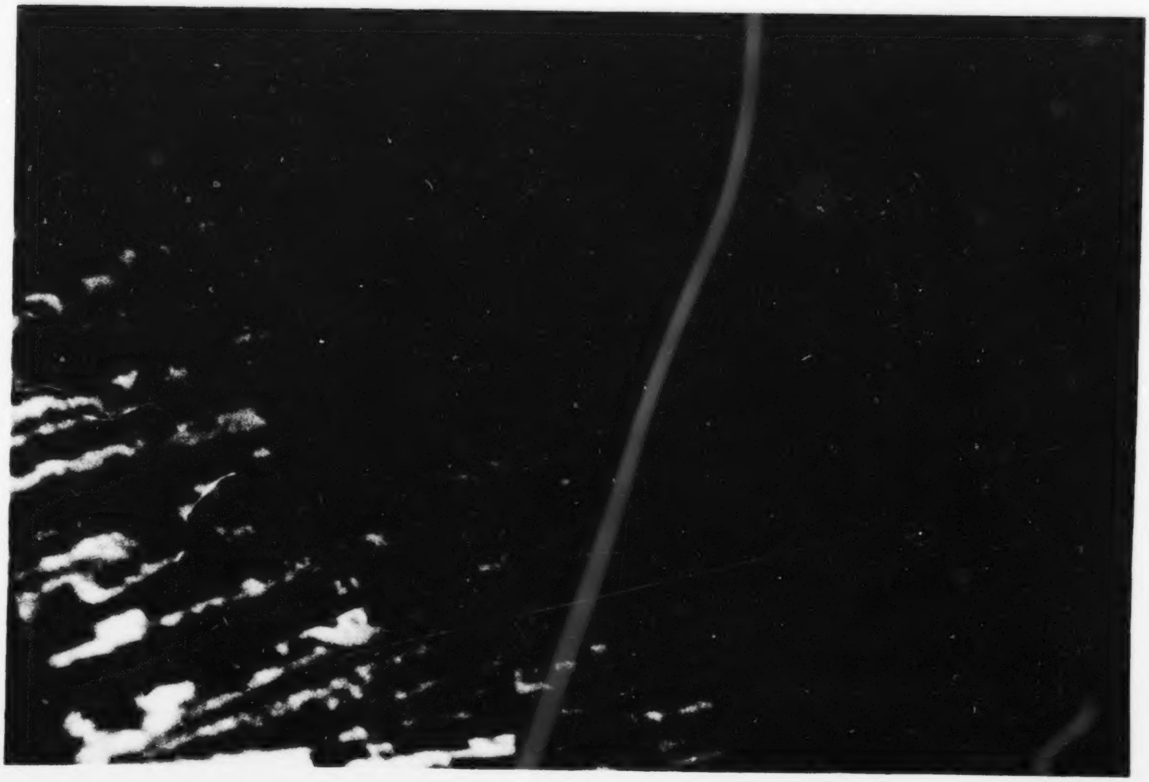
7. Liptinite - Sporinite & Resinite (dark) bodies in densinite matrix

X480 Ordinary light Bienfait 2

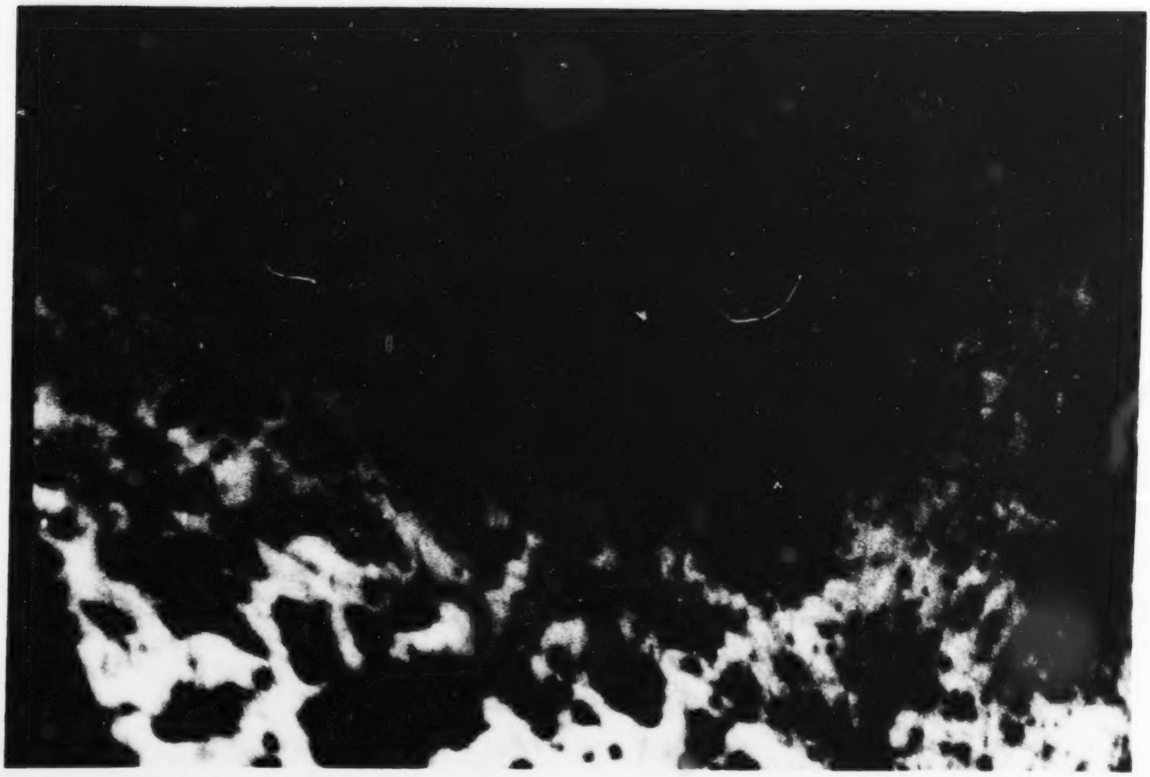
8. Structured huminite - Texto-ulminite and Eu-ulminite X480

Ordinary light Bienfait 2

9. Charred Structured huminite - Textinite X480 Ordinary light Utility 1

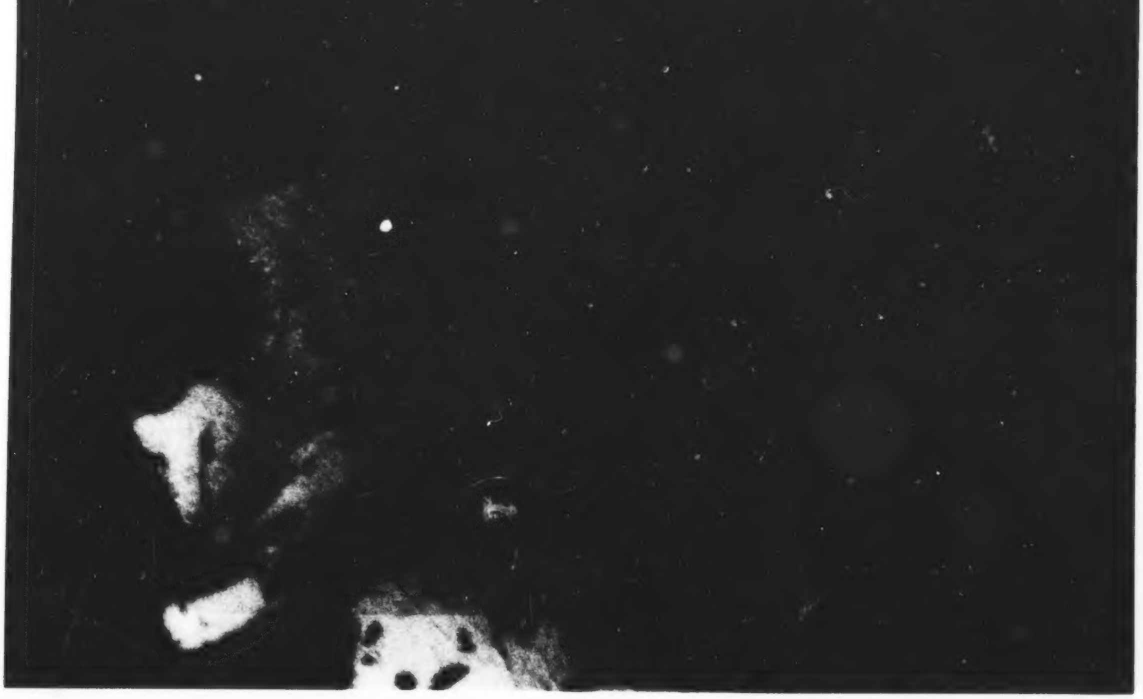


10. Charred Structured huminite - Textinite X480 Ordinary light Utility 1



11. Charred Structured huminite - Texto-ulminite & eu-ulminite X480

Ordinary light Utility 1



12. Charred Structured huminite - Eu-ulminite X480 Ordinary light Utility 1

13. Charred Unstructured huminite - Corpohuminite and eu-ulminite X480

Ordinary light Utility 1

14. Char of Structured huminite (Eu-ulminite (bottom left) with detrinite band (bottom right) containing charred sporinite (centre top) X480

Ordinary light Utility 1